Potato Processing

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Potato Processing

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in collaboration with a group of specialists

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Preface

The rapid expansion of the potato processing industry since 1946 is one of the significant developments in the food field during this period. Marked improvement in the quality of existing products and the rapid development and successful introduction of a wide variety of new frozen and dehydrated potato products have made this expansion possible. At the present time, the rapidly growing potato processing industry utilizes about one-fifth of all potatoes for food use. Responsible members of the industry predict that within a few years one-half of our potato crop will be utilized in processed form.

It is believed that this is the first book to be written covering all phases of potato processing including detailed descriptions of processing procedures for all types of frozen, dehydrated and canned products, a complete discussion of raw material storage problems, methods for selection of potatoes for processing, a thorough treatment of storage diseases, and an evaluation of most important potato varieties.

In preparing this book the authors have had the assistance of a number of collaborators, each a specialist and recognized authority in the field covered. As a result, each section has been written by an expert who has had years of experience and has devoted much time to the study of the topic about which he has written.

In preparing the book the authors have given special attention to processing procedures, equipment and the problems encountered in all types of potato processing so as to make it a most valuable reference book for those directly engaged in any type of potato processing. Other sections on storage, varieties, and handling make this book a valuable information source for those engaged in growing or supplying potatoes for processing. Technical information in this volume has been arranged so that it can be used as a text for college courses covering the handling, storage and utilization of potatoes.

References have been cited to establish authority and to assist the reader who may wish to obtain additional information about any particular subject. Obviously all references to the voluminous literature covering this field have not been cited. Careful attention has been given to provide reference to the most significant articles which have been published up to October, 1958.

The authors wish to acknowledge the assistance of the collaborators

who so generously contributed their time in preparing sections of the book and who have made available in summarized form their knowledge and wide experience in their respective fields. The authors are indebted to the numerous research workers whose work has been cited and drawn upon freely and to members of the American Can Company, the Continental Can Company, and the National Canners Association for information and counsel in preparing certain sections of the book.

All segments of the potato processing industry have been most generous in supplying photographs and information about their operation. The National Potato Chip Institute and its business and associate member companies, the Rogers Brothers Seed Company, the J. R. Simplot Company, and the J. D. Ferry Co. have been especially helpful. Published results of the Eastern and Western Regional Research Laboratories of the U. S. Department of Agriculture have been most useful as source material for the preparation of this book.

The authors are also indebted to Dr. A. Frank Ross, Messrs. Lyle C. Jenness, and M. T. Hilborn of the University of Maine for the analytical methods presented in the Appendix.

William F. Talburt
Ora Smith

January 1, 1959

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CHAPTER 1

William F. Talburt

History of Potato Processing

EARLY HISTORY

Potato processing is almost as old as the potato itself. Historians and archeologists are able to trace the potato, *Solanum tuberosum,* back to at least 200 A.D. at which time it was being cultivated in the mountainous areas of Peru. Even at that early date, the natives had found a way to dehydrate potatoes by allowing them to freeze at night and thaw during daylight hours. Juice was expressed from the thawed potatoes by treading on them with bare feet. This cycle was repeated several times and dehydration continued until the moisture content was reduced sufficiently to preserve the potatoes.

Almost two thousand years later this process was "rediscovered" and is now being used in the so-called "freeze and squeeze" process for the preparation of dehydrated potatoes in England.

For many centuries the potato served as the primary food source of the Indians of Peru. Apparently sufficient potatoes were dehydrated to provide for periods when potatoes were not available between successive crops or when shortages developed because of frosts or other unfavorable growing conditions. When the Spanish explorers arrived in the New World, the potato was quite widely distributed throughout South and Central America, Mexico and even up into the southern parts of the United States. However, there is no record that the potatoes were cultivated in any part of the New World outside of the Andean areas. The wild plants were recognized as sources of food and to some extent the tubers were utilized, but no evidence of domestication has been found.

Today the potato is cultivated in Peru as intensively as in Inca days before the advent of the Spanish and English explorers. In the Lima market it is reported that one may see some most extraordinary and unusual types of potatoes. There in Peru, the natives, through centuries of cultivation, have developed varieties that are scarcely recognizable as potatoes. Some are golden-yellow, others are purple, pink, pale lilac and blue, spotted and striped, round and oblong, crenated and cylindrical, and may be smooth-skinned or warty as toads.

INTRODUCTION INTO THE OLD WORLD

Spanish and English explorers recognized the great value of the potato at an early date and obtained them from the Indians for use in provisioning their ships. It was not too many years before potatoes were introduced into European countries. Records have been found which show that a hospital in Seville, Spain bought potatoes as early as 1573, although they may have been introduced several years earlier. Since all purchases were made in the fourth quarter of the calendar year, they were probably grown in Spain and freshly harvested (Hamilton 1934). Potatoes were probably regarded as a luxury in this country up to 1584. From Spain the tubers were carried to Italy and perhaps to other parts of Europe. In 1588 it is recorded that potatoes were being used in Italy as cattle feed.

The exact date and the method of introduction of the potato into England is a subject of considerable controversy but must have occurred during the closing years of the sixteenth century. For a number of years it was grown only in gardens and was used as a food on only a limited scale.

In spite of the fact that the potato was reputed to cause a number of diseases including leprosy, cultivation of potatoes in Ireland and, to a lesser extent, in England became quite extensive during the seventeenth century.

Potatoes were first introduced into the United States in 1621 when a shipment was sent to Virginia from Bermuda where they had been sent from England. In 1719 a group of Irish settlers brought potatoes with them to New Hampshire. Being so familiar with the potato, they did much to promote its cultivation and acceptance in New England.

In the eighteenth and nineteenth centuries when the potato became the major source of food in a large part of Europe, its two principal disadvantages—bulk and comparatively short storage life as compared with grain—became apparent. In Europe, experiments with various types of dried potato were made in the latter half of the eighteenth century partly with a desire to increase the usefulness of the tubers as ships' provisions. A sample of potato flour or meal was prepared in 1786 that "keeps sound for any length of time" (Fraser 1794).

Little was accomplished along this line either in Europe or the United States until World War I when a number of dehydrated potato products were manufactured for military use. This war industry practically disappeared soon after hostilities ceased although considerable quantities of potato flour, both for stock feeding and human consumption continued to be produced on the continent of Europe, and to a lesser extent in the United States and England.

Potato starch which utilizes substantial quantities of potatoes, has been produced both in Europe and in the United States for over 100 years. The

first starch plant was established in this country in 1831 and within a few years over 100 plants were producing potato starch.

FOREIGN AND DOMESTIC POTATO PRODUCTION

The potato, with a total production at the present in excess of 10 billion bushels, is one of the major food crops in the world. Because they yield heavily, are relatively inexpensive, and can be grown in a wide variety of soils and climates, potatoes are the mainstay in the diet of people in many parts of the world. The production of potatoes by countries is given in Table 1. Production figures for U.S.S.R. are not included in the table.

TABLE 1

WORLD PRODUCTION OF WHITE POTATOES BY COUNTRIES[1]

Country	Average, 1948–52	1955	1956
		1,000 Cwt.[2]	
Austria	50,000	66,000	71,000
Belgium	47,000	48,000	45,000
Czechoslovakia	160,000	174,000	212,000
Denmark	48,000	32,000	47,000
Finland	32,000	23,000	37,000
France	302,000	331,000	400,000
Germany (East and West)	820,000	770,000	915,000
Greece	8,000	9,000	10,000
Hungary	37,000	54,000	45,000
Ireland	64,000	47,000	58,000
Italy	60,000	74,000	75,000
Netherlands	103,000	90,000	75,000
Norway	26,000	22,000	31,000
Poland	654,000	594,000	838,000
Portugal	24,000	24,000	24,000
Romania	37,000	57,000	59,000
Spain	74,000	90,000	95,000
Sweden	40,000	28,000	46,000
Switzerland	23,000	24,000	33,000
United Kingdom	208,000	140,000	168,000
United States	234,000	227,000	240,000
Yugoslavia	32,000	50,000	48,000
Other countries	410,000	459,000	455,000
World Production (Exclusive of U. S. S. R.)	3,502,000	3,452,000	4,035,000

[1] From Anon. (1958).
[2] Converted from metric tons.

However, the area devoted to potatoes in Russia is reported to be (Anon. 1958) about 9,000,000 hectares or only about 30 per cent less than the total for the rest of the world. Agricultural statistics of the U. S. Department of Agriculture reports the average production of potatoes in the U. S. S. R. for the years 1935 to 1939 as 1.6 billion hundredweights.

No post-war figures on the overall disposition of potatoes outside this

country have been found. Per capita consumption of potatoes in certain selected countries is shown in Table 2.

TABLE 2

PER CAPITA CONSUMPTION OF POTATOES, POUNDS, SELECTED COUNTRIES, AVERAGES 1934–39, ANNUAL 1947 AND 1948[1]

Country	Average 1934–38	Average 1935–38	1947–48	1948–49
		Lbs.		
Germany				
All	...	388.0	...	...
Bizone	...	...	337.1	...
French zone	...	...	379.2	...
Soviet zone	...	...	453.7	...
East	...	...	...	479.9
West	...	...	...	483.5
Ireland	430.8	...	434.5	428.8
France	341.9	...	348.3	316.1
Poland	628.3	...	...	528.4
Finland	398.6	...	339.1	405.7
Belgium	371.9	...	315.0	311.1
United States	...	123.9[2]	111.8	96.8

[1] From Food Balance Sheets, Food and Agriculture Organization of the United Nations. Washington, D. C. 1949 and 1950.
[2] For the period 1935–39.

Werner (1930) stated that in Germany over 38 per cent of the potato crop was used for stock feeding compared with only 38 per cent for human food. In general, on the continent of Europe, some 20 to 50 per cent of potato production is normally fed to stock (Yates 1940), while in Ireland, almost 60 per cent is used for stock feeding (Kennedy 1941). It seems reasonably safe to assume that much the same situation exists at the present time since potato production in Europe has increased in about the same proportion as has its population, and since there is no reason to assume that food uses of potatoes have changed markedly during the past thirty years.

It is interesting that the average annual production of potatoes in the United States is about 225 million hundredweights, or about 130 lbs. per person. Approximately 100 lbs. of this is actually consumed as food. By contrast, production in Poland in 1956 was 838 million hundredweights or about 3350 lbs. per person. Although food use of potatoes throughout Central Europe is very high, large quantities of potatoes are obviously employed in livestock feeding, in starch production, and in the manufacture of alcohol.

RECENT TRENDS IN POTATO PROCESSING

In this country, per capita consumption of potatoes reached a maximum of 180 lbs. in 1910 and has dropped rather sharply since that time. For

the past few years there is an indication that this decline has been halted with per capita consumption constant at about 100 lbs. Consumption pattern for potatoes for the past century is shown in Fig. 1. Statistics in this field were not gathered by the U. S. Department of Agriculture prior to 1910. Figures prior to that time are based on Department estimates.

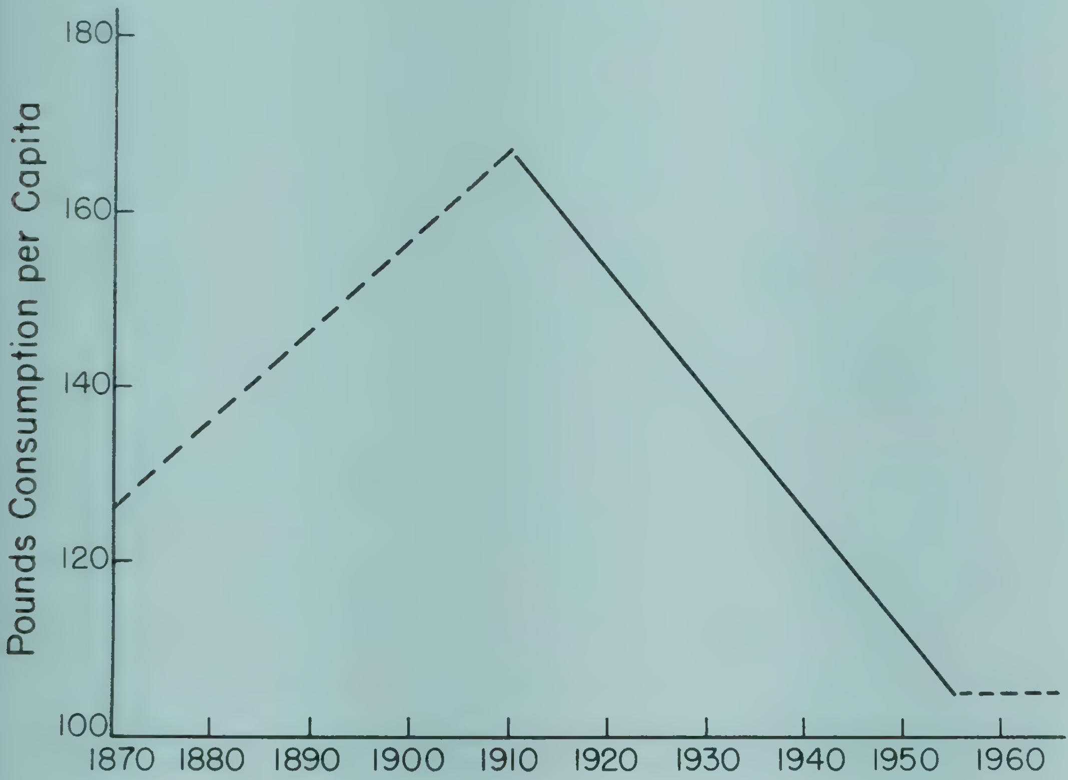

FIG. 1. PER CAPITA CONSUMPTION OF POTATOES SINCE 1870

Statistics prior to 1910 were not collected by U. S. Department of Agriculture; figures are based on Department estimates.

The rise in per capita consumption from 1850 to 1910 is undoubtedly largely attributable to the heavy influx of North European immigrants into the United States during this period. Had this heavy immigration not occurred, annual per capita consumption in 1910 might have been well below 180 lbs. However, there is no reason to believe that this wave of immigration has greatly altered the post-war level of consumption since there has been little immigration into this country for well over a generation. During this period, the adjustment in eating habits by these immigrants was superimposed on a developing economic situation which already was exerting a downward pressure on potato consumption. These two factors resulted in a decrease in per capita consumption which offset the effect of

population increases on total consumption of potatoes from 1910 through 1950. There is reason to believe that the effects of these factors may now be diminishing to a point where per capita consumption of potatoes has been fairly well stabilized, and that with the rapid increases in processing and the greater availability of a larger variety of processed products, per capita consumption of potatoes may rise in the future.

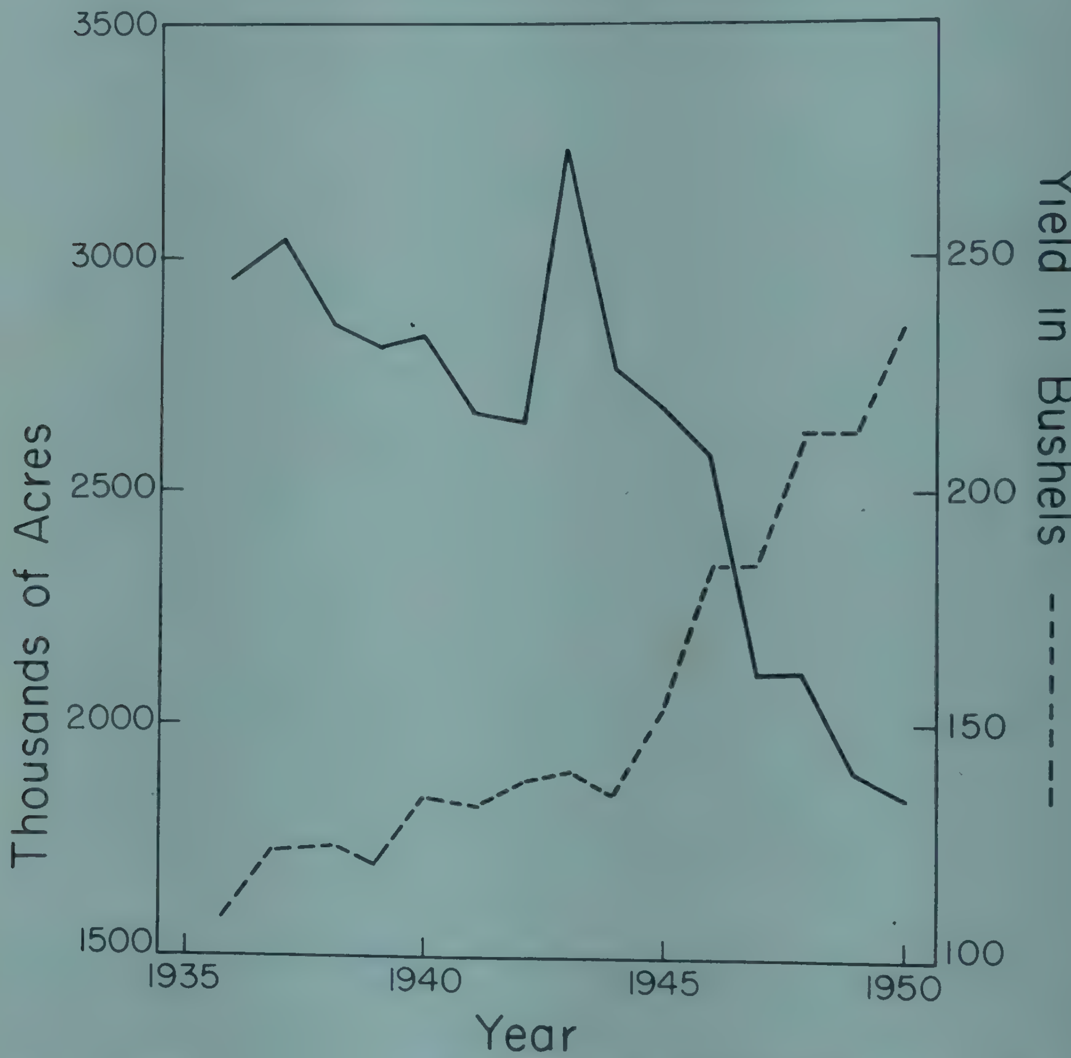

Fig. 2. Trends in Acreage Planted and Yields of Potatoes During Recent Years

Another very significant trend in the production of potatoes in this country has been the steadily rising yield which has increased from 67 hundredweights per harvested acre in 1920 to 176 hundredweights in 1956. Since the total production of potatoes has not changed greatly during this period, there has been a corresponding decrease in the number of acres planted to potatoes. This is shown in Fig. 2. Prices received by the

growers during this period have fluctuated widely between $0.625 and $3.25 but have not advanced to any great extent.

The amount of potatoes processed in the United States has increased at a phenomenal rate since 1940. Figures on the production and disposition of our supply of potatoes for a number of post-war years are shown in Table 3.

Per capita consumption of processed potatoes has increased from 1.9 lbs. in 1940 to 23.4 lbs. in 1956 and has more than doubled during the period 1949 to 1956. Potato chips utilize about two-thirds of the potatoes that are processed for food uses but dehydrated and frozen products are rapidly becoming more important as processed potato products.

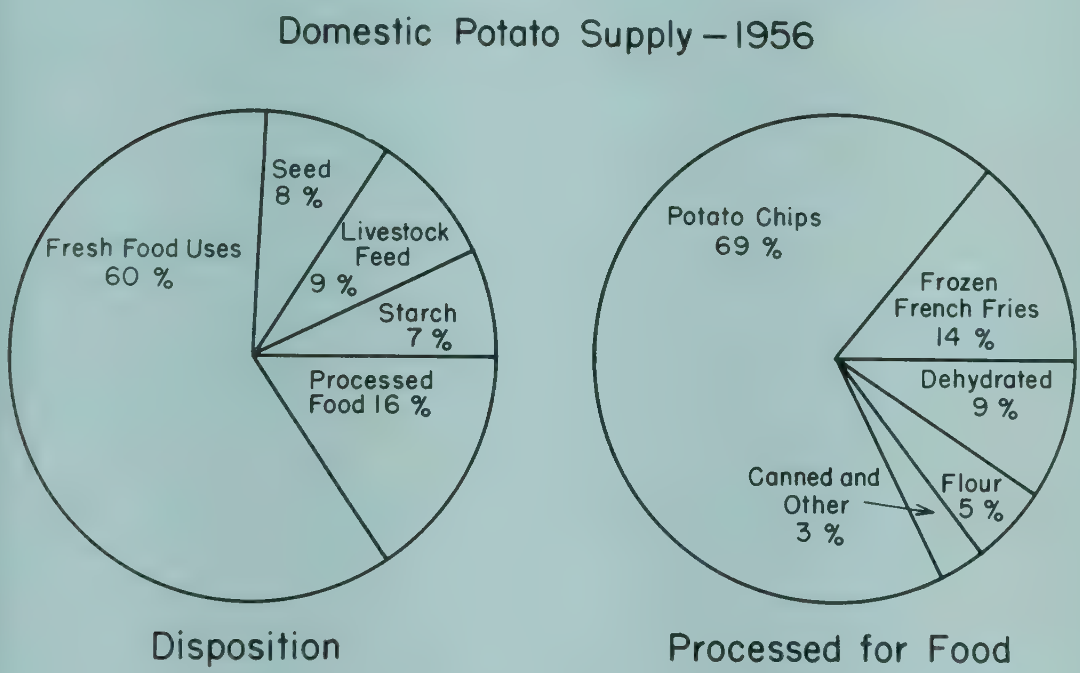

FIG. 3. DISPOSITION OF DOMESTIC POTATO SUPPLY

Potato chips which were first made in this country about the middle of the nineteenth century were originally called Saratoga chips. For a number of years they were prepared only by the housewife in her own kitchen. Small scale commercial production was later carried on for a number of years but did not really develop to any great extent until improved peeling and frying techniques were developed. In 1939 the industry used only 3.5 millions of bushels of potatoes. The industry grew rapidly during the war years using 12 million bushels in 1944 and currently requires about 45 million bushels of potatoes per year to supply its many large continuous fryers.

TABLE 3

PRODUCTION AND DISPOSITION OF POTATOES[1,2]

Crop Year→	1940	1949	1950	1951	1952	1953	1954	1955	1956[3]
	1,000 Bushels								
Production	376,920	401,583	431,940	326,359	351,895	386,209	365,985	378,486	405,397
Imports	930	10,100	5,349	2,309	3,283	2,924	1,780	3,648	2,700
Total Supply	377,850	411,683	437,289	328,668	355.178	389,133	367.765	382,134	408,097
Exports	2,495	11,462	5,534	6,707	4,366	4,603	7,123	6,590	6,697
Shipments to Territories	1,788	879	1,109	1,074	1,033	1,105	1,407	1,309	1,400
Total Off Shore Sales	4,283	12,341	6,643	7,781	5,399	5,708	8.530	7.899	8,097
Available Domestic Use	373,567	399,342	430,646	320,887	349,779	383,425	359,235	374,235	400,000
Used for Seed	41,985	35,823	29,079	31,050	35,689	32,221	33,163	32,465	32,000
Fed to Livestock	37,238	76,216	100,869	19,664	21,761	32,320	26,167	28,395	35,600
Starch	8,030	12,975	21,682	4,701	8,264	16,500	11,000	20,752	29,000
Alcohol	...	763	...	...	...	...	...	...	...
Total Non-Food Use	87,253	125,777	151,630	55,415	65,714	81,041	70,330	82,112	96,600
Total Food Use	286,314	273,565	279,016	265,472	284,065	302,384	288,905	292,123	303,400

Military Use—Fresh	...	5,000	8,000	9,900	7,900	7,700	7,000	7,000	7,000
Est. Civilian Use	286,314	268,565	271,016	255,572	276,165	294,684	281,905	285,123	296,400
Processed[4]									
Flour	400	1,147	1,200	500	400	1,550	2,600	2,900	3,000
Dehydration	...	582	3,081	2,620	1,220	3,400	3,000	4,700	6,000
Canning	...	830	865	1,000	1,450	1,330	800	1,300	1,400
Hash, Stews, Soups	500	1,500	1,500	1,200	1,000	1,000	800	800	800
Frozen French Fried	...	900	1,200	2,000	2,400	2,700	3,600	7,700	9,000
Potato Chips	4,500	20,100	21,200	22,760	25,250	29,000	32,000	39,346	45,000
Total Processed	5,400	25,059	29,046	30,080	31,720	38,980	42,800	56,746	65,200
Est. Sold to Restaurants[1]	40,000	56,000	57,500	59,000	60,000	63,000	64,000	65,000	65,000[5]
Total Use for Processed and Restaurants	45,400	81,059	86,546	89,080	91,720	101,980	106,800	121,746	130,200
Est. Total Used Fresh in Homes	240,914	187,506	184,470	166,492	184,445	192,704	175,105	163,377	166,200
Used on Farms	63,099	29,785	29,073	24,912	21,746	20,886	21,209	20,703	20,000
Purchased Fresh for Home Use	177,815	157,721	155,397	141,580	162,699	171,818	153,896	142,674	146,200
Civilian Pop. July 1 (Millions)	134.0	149.6	152.3	153.2	155.5	158.3	161.3	164.5	167.5
Per Capita Consumption Crop Yr.	128.0	107.7	106.8	100.1	103.0	111.7	104.9	104.0	106.2
Per Capita Consumption Calendar Yr.—Pounds	121.0	109.0	102.0	108.0	99.0	103.0	106.0	103.0	101.0
Per Capita Pounds Processed Used as Food—Pounds	1.9	10.1	11.4	11.8	12.2	14.8	15.9	20.7	23.4

[1] Released by the National Potato Council.
[2] Source: Agricultural Marketing Service except as noted.
[3] Dec., 1956 U. S. Dept. Agr. Crop Report.
[4] Industry estimates.
[5] Includes an estimated 4,000,000 bushels of prepeeled potatoes.

The amounts of potatoes used in different processed potato products in 1956 are shown in Fig. 3.

Processing utilized about 65 million bushels of potatoes in this year or in excess of 20 per cent of all potatoes for food use.

FUTURE OF POTATO PROCESSING

Many potato producers are raising questions about the future of the processed potato industry, its effect on consumption levels of fresh potatoes, and effects of these changes on individual producers in different areas of production. To provide an answer to these questions is obviously a complex task for which more information is needed than is now available.

The importance of the general level of consumer incomes in answering these questions is indicated by a survey of food consumption in households of the United States (Anon. 1955). According to that study, during one week in the spring of 1955, only 2.5 per cent of the households with a family income of $3,000 to $4,000 used frozen potato products while 13.5 per cent of the households with $10,000 and over of income used these products. For canned and dehydrated and sweet potatoes, 3.3 per cent of the families with $3,000 to $4,000 of income and 6 per cent of those making over $10,000 bought these products.

In the case of potato chips and sticks, the proportion was 24.7 per cent for the lower income group and 38.9 per cent for the higher income group. These data indicate that except for potato chips, only a small percentage of the families were using these products at the time and that there are possibilities for great expansion of all these products, including the well established potato chip.

Production of potato chips has been increasing steadily though not spectacularly each year so that the industry is prosperous and looking forward to continuing expansion for a number of years. Studies of potential demand for dehydrated mashed potatoes indicate a considerable potential market for these products. Also, processors report that they find an expanding demand for dehydrated diced potatoes and a potential for considerably increased sales. Currently limited emphasis is being placed on promoting dehydrated products since markets are readily absorbing current supplies with little advertising. While potato flakes, a newly developed dehydrated mashed potato product, have been on the market only a short time, plants in Idaho, Maine, New York, Oregon and California will soon be producing this product in substantial quantities.

High and rising levels of consumer income and the increasing number of women employed in our expanding industrial system would seem to favor continuing expansion of the demands for processed potato products.

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and Horace K. Burr

Structure and Chemical Composition of the Potato Tuber

ANATOMY OF THE TUBER

The anatomy of the potato plant, including the tuber, has been described in detail by Artschwager (1918 and 1924) and others. The tuber itself is essentially an abruptly thickened underground stem closely resembling the aerial stem of the plant. Fig. 4 shows the organization of the principal internal tissues of the mature tuber. The outer skin consists of a layer of corky periderm, some 6–14 cells deep, which appears to serve the purpose of retarding loss of moisture and resisting attack by fungi. When a potato is cut or otherwise wounded, proliferation of cells at the surface forms "wound periderm," which is said to be even more effective than normal periderm in performing these functions. Wound periderm formation is retarded in tubers which have been exposed to gamma radiation (Waggoner 1955) or treated with certain sprout inhibitors (Cunningham 1953).

Underlying the periderm is the cortex, a narrow layer of parenchyma tissue. Vascular storage parenchyma, high in starch content, lies within the shell of cortex. Xylem and phloem are found in minute strands or bundles, most of which form a narrow, discontinuous ring ("vascular ring") somewhat within the boundary between the cortex and the vascular area. Forming a small central core but radiating narrow branches to each of the eyes, is the pith, sometimes called the "water core." It consists primarily of large cells containing less starch than cells in the vascular area and the innermost part of the cortex.

Externally the tuber clearly shows its relation to the aerial stem. Each eye is a rudimentary scale leaf or leaf scar with its axillary buds. As on the stem, these are arranged in a right-handed or left-handed spiral around the tuber, 13 eyes to 5 turns of the helix (5/13 phyllotaxy). Each eye contains at least three buds together with protecting scales. When a normal tuber sprouts, it is the eye at the "bud" end, corresponding to the growing tip of a stem, which develops first. Sprouts develop at few, if any, of the

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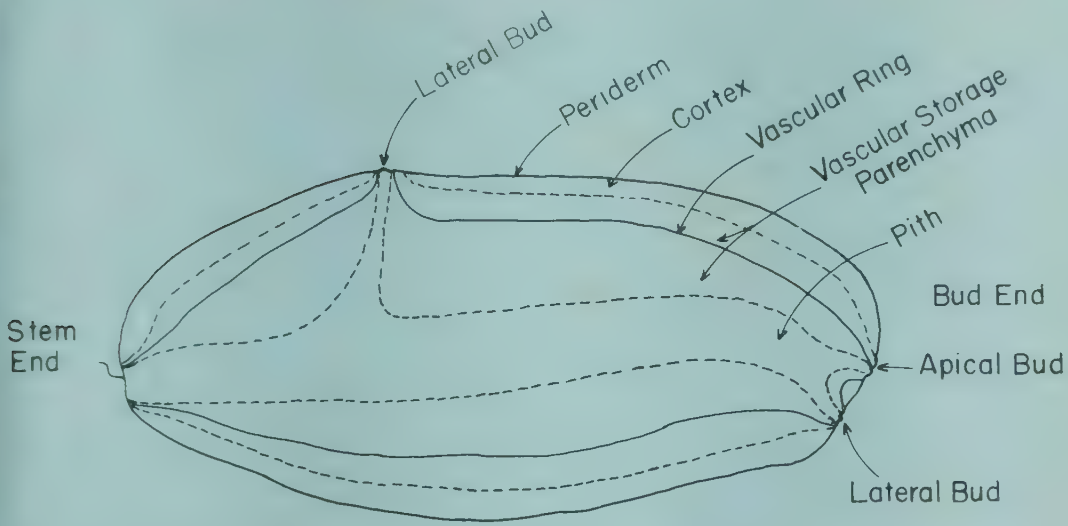


FIG. 4. LONGITUDINAL SECTION OF A RUSSET BURBANK POTATO SHOWING PRINCIPAL STRUCTURAL FEATURES

other eyes under normal circumstances. This "apical dominance" may be suppressed in tubers which have been exposed to small doses of gamma radiation (Schwimmer *et al.* 1957A). If a tuber has been cut into pieces, as when potatoes are planted, sprouts will appear at one or more eyes on each piece.

PROXIMATE ANALYSIS AND MINERAL CONTENT

The literature on the chemistry of the potato is extensive. Kröner and Völksen (1950), for example, cite over 1,350 references. From this mass of data it is difficult to obtain a clear picture of the composition of the potato, for not only does this vary with variety, area of growth, cultural practices, maturity at harvest, subsequent storage history, and other factors, but the methods of analysis used by different investigators have varied greatly. As has been pointed out (Lampitt and Goldenberg 1940), some workers have analyzed the whole potato, while others have used

TABLE 4

PROXIMATE ANALYSIS OF WHITE POTATOES

	Average Per cent	Range Per cent
Water	77.5	63.2 –86.9
Total solids	22.5	13.1 –36.8
Protein	2.0	0.7 – 4.6
Fat	0.1	0.02– 0.96
Carbohydrate		
Total	19.4	13.3 –30.53
Crude fiber	0.6	0.17– 3.48
Ash	1.0	0.44– 1.9

TABLE 5

COMPOSITION OF ASH[1] FROM WHITE POTATOES

	Average Per cent	Range Per cent
K_2O	56	43.95–73.61
P_2O_5	15	6.83–27.14
SO_3	6	0.44–10.69
MgO	4	1.32–13.58
Na_2O	3	0.07–16.93
CaO	1.5	0.42– 8.19
SiO_2	1	0.16– 8.11

[1] Other mineral elements which have been reported as present in the potato are, roughly in descending order of concentration: Cl, Fe, Al, Mn, Zn, Cu, B, Br, Ti, Ni, Mo, Co, As, Hg, Ra.

peeled tubers. Although it is probable that most analyses were made on whole potatoes, in many instances the reports are not explicit on this point. Since peeling may remove as much as 20 per cent of the potato, including much of the important cortical layer, it is apparent that this experimental factor may contribute to variation between reported results.

Table 4 gives the proximate composition of the potato, and Table 5, the mineral content of potato ash. The values are based on those given by various reviewers (Kröner and Völksen 1950; Lampitt and Goldenberg 1940; Brautlecht and Getchell 1951; Watt and Merrill 1950) and are ultimately derived from data subject to all the sources of variation mentioned above. For this reason they must be regarded as only approximate.

STARCH

Starch, comprising some 65 to 80 per cent of the dry weight of the potato tuber, is calorically the most important nutritional component. The content, and the physical, chemical and histological characteristics of the starch are not only intimately associated with various parameters involved in the quality of the processed products, but also they dictate operational conditions of the processes. In the raw tuber, starch is present as microscopic granules in the leucoplasts lining the interior of the walls of the cells of the parenchyma tissue. The granules are ellipsoidal in shape, about 100 microns by 60 microns on the average. They are thus much larger than the average starch granules of cereal grains. Actually, there is a wide range in sizes, the smallest measuring less than five microns in the long axis (Briant *et al.* 1945; Brautlecht 1953). Starch granules as large as 170 microns have been found to be present in potatoes treated with plant growth hormones (Kröner and Völksen 1950). The starch granule resembles an oyster shell in appearance due to apparent striations on the surface as observed under the microscope (see Fig. 5). The focus of these striations, the hilum, is also the focal point for attack by amylolytic enzymes (Schwimmer 1945). Recent electron micrographs of the

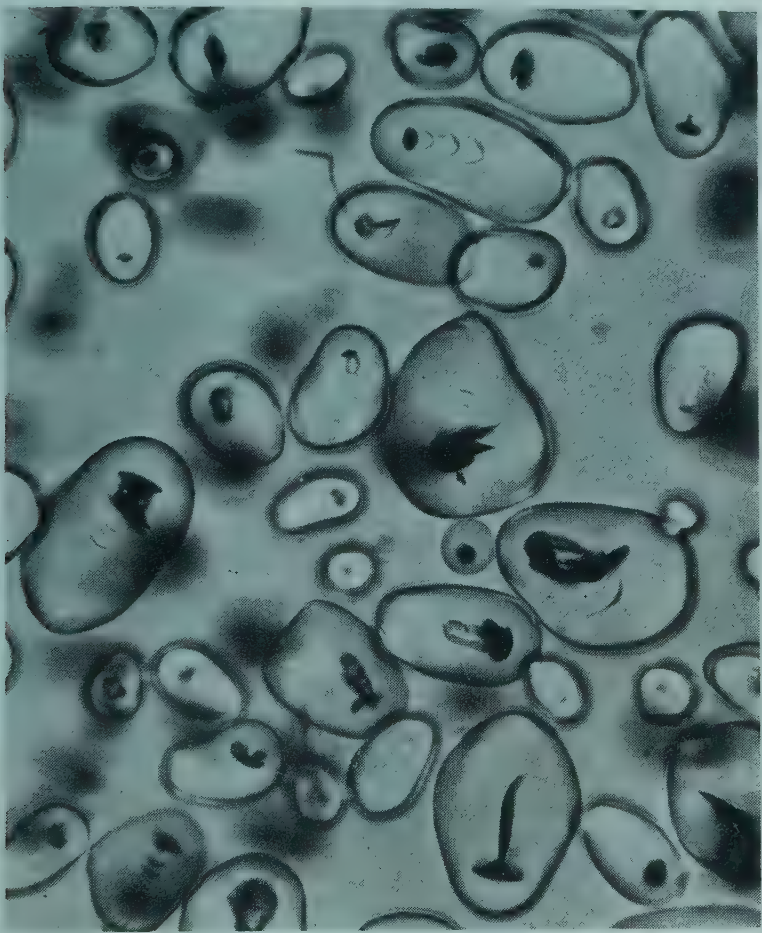


FIG. 5. STARCH GRANULES FROM RUSSET BURBANK POTATOES
× 310

Note "oyster shell" striations.

potato starch granule reveal a surprisingly smooth surface structure (Whistler *et al.* 1955).

The size distribution seems in general to be independent of the location within the tuber, although it has been reported that the largest granules are found in the vascular areas (Johnson and Boyle 1918). Small grain size has been associated with: dry season, small tubers, immaturity, potassium deficiency, and prolonged post-harvest storage (Burton 1948). Size and size distribution of the granules probably contribute to the character and quality of the cooked potato (Briant *et al.* 1945).

Chemical Composition

By appropriate procedures the starch granules can be isolated in the laboratory (Cowie and Greenwood 1957) or on a commercial scale (Brautlecht 1953). The dry matter of the granule consists of 99.5 per

cent starch, 0.3 per cent ash, and 0.01 per cent nitrogen (Kröner and Völksen 1950). The two main or perhaps sole components of the starch, amylose and amylopectin, are present in a ratio of 1:3 (McCready and Hassid 1947). This ratio, which seems to be fairly constant, although slight varietal differences have been reported, is affected by neither time nor temperature of storage (Schwimmer *et al.* 1954). Amylose is a polydisperse polymer of α-1,4-linked glucosyl residues (with slight branching) (Potter and Hassid 1948; Stepananko and Afanosyeva 1957) whose average degree of polymerization has been reported variously as 1,000 to 5,000 depending upon the source of tuber and the method of measurement and preparation (Bottle and Gilbert 1954). Thus it appears that amylose prepared from commercial starch has significantly shorter chains than that from starch more carefully prepared in the laboratory.

Amylopectin is a branched-chain glucose polymer in which the α-1,4-linkages are branched by an α-1,6- linkage (Schwimmer and Bevenue 1956) every 20 glucosyl residues on the average. This gives rise to a highly branched molecule whose average degree of polymerization is of the order of magnitude of 100,000 (Potter and Hassid 1948). The orientation of the amylose within the granule is considered to be responsible for the crystallinity of the starch granule (Kerr and Cleveland 1952).

Of the minor constituents of the starch granule only phosphorus has been shown to be chemically combined with the starch (Posternak 1951). The trace of nitrogen apparently arises from the protein debris of the leucoplasts and cytoplasm (Willigen and Groot 1954). Although phosphorus represents only a small percentage of the starch granule, as much as one-third of the total phosphorus of the potato may be combined with starch (Schwimmer *et al.* 1955). The amount of starch phosphorus has been said to be a varietal characteristic, but it also depends on the phosphorus content of the soil and perhaps on the total phosphorus content of the tuber (Willigen 1954). Smaller starch granules contain more phosphorus than larger ones (Kröner and Völksen 1950).

It has been definitely shown that the phosphorus is present as orthophosphate esterified with the hydroxyl of the C-6 position of a glucosyl residue of the amylopectin moiety of the potato starch (Posternak 1951). About one in every 200 glucose units is thus esterified. The amylopectins of the grain starches do not contain esterified phosphate. The viscosity of gels prepared from potato starch seems to be closely correlated with the phosphorus content of the starch (Veselovsky 1940; Willigen 1954).

Starch Content and Distribution of Starch in the Potato

It has been repeatedly demonstrated that there is a close correlation among specific gravity, total solids, and starch content. This is due to

the fact that starch comprises a major proportion of the dry matter and that the percentage of non-starch solids in the fresh tuber is relatively constant, around 6 per cent (Burton 1948). Most factors which tend to increase the specific gravity and total solids content of the tuber therefore increase the starch content, both on a fresh weight basis and as a percentage of the dry matter. Isleib (1958) has shown that differences in the specific gravity between varieties are not due to differences in the density of the starch or in granule size.

Von Scheele *et al.* (1937) derived the following equation for estimating starch content from measurement of the specific gravity:

$$\text{Percentage starch} = 17.546 + 199.07 \times (\text{Sp. Gr.} - 1.0988)$$

The coefficient of correlation was +0.947 for 560 samples of potatoes grown in Sweden. The relation between specific gravity and starch content did not differ significantly between varieties, nor was it influenced by year or area of production.

In view of the importance of the starch of the potato and the ease with which its correlate, specific gravity, can be measured, it is not surprising that hundreds of papers on factors affecting these characteristics have been published. It was firmly established at an early date that starch content is a varietal characteristic, all other controllable factors being equal. The following additional factors have been reported to be associated with increased specific gravity or starch content:[1]

Fertilization.—Manuring; high ratios of potassium to nitrogen (Eastwood and Watts 1956), potassium to phosphorus (Lucas *et al.* 1954), and sulfur to chlorine (Timm 1957).

Cultural Conditions.—Low soil moisture; short day, shading, close spacing, early planting date (Burton 1948); optimum soil temperatures of 59° to 65°F. (Buzover 1956); late killing of vines (Akeley *et al.* 1955); vernalization (Volkov 1956).

Freedom from Disease.—See Whitehead *et al.* (1953); Rubin *et al.* (1956); and Emilsson and Gustafsson (1956).

Morphology.—Tubers of long cylindrical shape; russetted skins; arched eyes (Kröner and Völksen 1950).

Internal Distribution.—Vascular area, stem area.

In connection with cultural conditions, increased starch content is not always compatible with high yields. Thus long days and adequate nitrogen are propitious for high per acre yields and development of the haulm, whereas short days and low nitrogen lead to increased starch content. In

[1] Reviews of the older literature have been made by Burton (1948) and by Kröner and Völksen (1950).

general, it appears that many of these environmental factors do not have as great an influence on the starch content as variety can have.

Enzymes of Starch Metabolism

Starches elaborated in the leaves of the potato plant are translocated to the growing tuber. The energy requirement of the dormant tuber in the post-harvest stage and during the initiation of sprouting is derived from the enzymatic reactions starting with starch as the parent substance.

The enzymes involved in the synthesis and degradation of potato starch have been reviewed by Schwimmer (1953).

Relation to Processing and Utilization

Investigation of the relationship between starch and texture began about 60 years ago when it was suggested that the ratio of starch to nitrogen in the tuber was a measure of the textural quality of the boiled potato (Coudon and Bussard 1897; Burton 1948). It has become increasingly clear that there is indeed a highly significant correlation between the starch content of the raw tuber and various attributes of textural quality such as mealiness, consistency, sloughing, and lack of sogginess (Kirkpatrick *et al.* 1951; Unrau and Nyland 1957). This suggests that the properties of starch and the changes these properties undergo during cooking are to be considered in attempting to explain variations in texture.

When the temperature of a potato is raised to above 122°F., water passes from the non-starchy parts of the cell into the starch granule, which then starts to swell. The starch will begin to gelatinize in the range of 147° to 160°F. (Roberts and Proctor 1955). In potatoes of high starch content, the cells tend to separate and round off largely because of the swelling of the gelatinized starch. In potatoes of low starch content, the cells tend to retain their original orientation with respect to each other. This results in sogginess. It is the amount of starch in the individual cell rather than the total amount of starch in the tuber that is related to the mechanism of cell separation (Whittenberger 1951). Other factors related to cell wall strength and composition which influence texture will be mentioned later.

Excessive cell separation, which is most pronounced in the cortical region of the tuber, results in "sloughing." This sloughing tendency is important not only in the cooking of the potato, but also in external sloughing encountered with commercial methods of peeling by heat and lye scald (Reeve 1954).

The starch content of boiled potato tissue is lower than that of the corresponding fresh tissue (Bettelheim and Sterling 1955A). This may be due in part to swelling of the starch and resulting cell rupture and leaching. Excessive rupture of cells with concomitant escape of gelled

starch causes a gummy texture in the cooked tuber. The influence of gelled starch can be controlled and modified by the rate and degree of heat treatment and by regulating the amount of available water (Whittenberger and Nutting 1948). The properties of the gel thus dictate to some extent the time schedules for heating and drying in different processes for potato dehydration. Thus in the manufacture of potato flakes it is often beneficial to interpose a precook for 15 to 30 minutes at 150° to 165° F. before final cooking and mashing (Willard *et al.* 1956).

In the manufacture of potato granules it has been shown that the changes in the solubility and swelling power of the starch of cooked potato starch gels parallel an increase in the completeness of granulation and an improvement in product quality (Potter 1954). Consistency of reconstituted potato granules has been shown to be related to the proportion of broken granules and hence soluble starch, an excess of which results in a pasty product (Mullins *et al.* 1955; Cooley *et al.* 1954). Certain aspects of the quality of fried potato products are apparently associated with high starch content. Thus potatoes of high specific gravity in general give French fries that are crisper and less oily, and have better flavor than those prepared from tubers of low specific gravity (Kirkpatrick *et al.* 1956). The relationship of specific gravity to yield and quality of potato chips is discussed in Chapter 10.

The high starch content of potatoes makes the manufacture of potato starch economically feasible, especially in Europe. In this country potato starch is usually manufactured from culls and damaged potatoes. Further expansion of the potato starch industry depends upon finding new modifications which can command higher prices. The high viscosity of potato starch, in part due to the presence of phosphorus, makes it desirable where high viscosity gels are desired (Willigen 1954). Improved solubility and other desirable properties, such as chemical reactivity, can be imparted economically to potato starch by recently developed oxidation procedures (Sloan *et al.* 1956). Recent investigations have indicated that potato starch is also suitable for use in the manufacture of allyl starch (Yanovsky 1953), candy syrups (Borud *et al.* 1956), and textile sizing (Kerr 1950). Recent comparisons of the properties of potato starch prepared in the laboratory (gel strength, gel clarity, amylose chain length) with those of commercial potato starch suggest that a gentler treatment in the commercial manufacture would aid in the development of better products from potato starch (Whittenberger and Nutting 1948; Bottle *et al.* 1953).

SUGARS

The sugar content of potatoes may vary from only trace amounts to as much as ten per cent of the dry weight of the tuber and thus 1/3 to

1/2 of the non-starch solids (Barker 1938). The two main factors which influence sugar content of potatoes during post-harvest storage are variety and temperature. Varieties which have a low specific gravity in general tend to accumulate more sugar than varieties of high specific gravity. Freshly harvested mature tubers may contain only traces of sugar, whereas certain varieties of tubers harvested prior to full maturity may have as much as 1.5 per cent sugar. Small tubers are said to contain higher percentages of sugar than do large tubers (Kröner and Völksen 1950). Upon storage of freshly harvested tubers at 68° to 86°F. there is a slight rise in total sugars to perhaps 1.5 per cent. At storage temperatures below about 50°F., the total and reducing sugars increase, the rate and extent of increase being greater the lower the temperature down to the freezing point. After about four to eight weeks at these low temperatures a maximum sugar concentration is reached, amounting to as much as ten per cent in such sugar-rich varieties as White Rose and to about three per cent in poor sugar accumulators such as Russet Burbank (Schwimmer *et al.* 1954). In the latter variety the sugar content may almost double following irradiation with gamma rays (Schwimmer *et al.* 1957A). Sugar content goes down during germination. There is more sugar in the center of the potatoes than in the outer portion (Kröner and Völksen 1950).

In contrast to the influence of cultural conditions and of fertilization practices on the starch content of potato, the sugar content correlates rather poorly with such factors as type of fertilizer, location, irrigation, etc. (Kröner and Völksen 1950). Tubers stored at low temperature in carbon dioxide undergo a preliminary retardation of sugar build-up followed by an increased rate of sugar production as compared with potatoes stored in air (Denny and Thornton 1941). Application of naphthalene acetic acid and chemicals which break dormancy tend to increase the sugar content (Denny *et al.* 1942). Sprout inhibitors such as maleic hydrazide have a variable effect, depending upon time of application and concentration of applied chemical (Gooding and Hubbard 1956; Payne and Fults 1955).

According to the older literature sucrose, glucose, and fructose are usually present in the potato in approximately equal amounts. More recent results indicate that during the initial stages of storage at low temperatures sucrose seems to accumulate most rapidly; and upon prolonged storage the ratio of sucrose to reducing sugar tends to increase with decreasing temperature (Burton 1948). Sucrose also accumulates preferentially in potatoes exposed to gamma radiation (Schwimmer *et al.* 1957A and 1958).

When tubers which have been stored at low temperatures are condi-

tioned at higher temperatures, the sugar content gradually decreases over a period of 3 to 4 weeks. Since the percentage of sugar decreases and the percentage of starch increases during conditioning, it has been tacitly assumed that the sugar is reconverted into starch. However, the percentage of starch would also increase if all of the sugar is lost through respiration.

In the above discussion we have been proceeding on the assumption that the reducing power of potatoes prepared for analysis is solely attributable to glucose and fructose, and that these, together with sucrose, make up the total sugars. Recent chromatographic results indicate that this is not strictly true. There are several non-sugar components present in such extracts which could conceivably react as reducing sugars. These include tyrosine, ascorbic acid, cysteine, glutathione, and inositol (Schwimmer *et al.* 1954). Secondly, reducing sugars other than glucose and fructose have been reported to be present. These include xylose and maltose, and certain of the sugar phosphates (Habib and Brown 1957; Schwimmer *et al.* 1955; Schwimmer and Bevenue 1956). Where deionized preparations derived from ethanolic extracts of potatoes have been used, these sugars have not been detected (Schwimmer *et al.* 1954). These deionized extracts do, however, contain sugars other than glucose, fructose, and sucrose, as evidenced by paper chromatography. These sugars include a seven carbon heptulose, present in all varieties tested at all storage temperatures. Raffinose, melibiose and melezitose in trace amounts also have been frequently found to be present. Only in potatoes with very low total sugar content do these trace sugars contribute significantly to analytical values for total sugar.

It is apparent from the above discussion that simple chromatography is not sufficient to establish the identity of sugars in the potato tuber other than glucose, fructose, and sucrose.

Enzymes of Sugar Metabolism

Considering the huge literature on the sugars of potatoes, it is perhaps surprising that complete information is not available concerning the enzymes responsible for the formation and removal of the sugars. The known potato enzymes involved in the transformation of the sugars of potatoes have been reviewed by Schwimmer (1953). Since this time the reactions leading to sucrose synthesis in plants, including potato sprouts, have been elucidated (Cardini *et al.* 1955). The final reaction leading to the formation of sucrose is:

$$\text{Uridine diphosphate glucose} + \text{Fructose} \rightleftharpoons \text{Sucrose} + \text{Uridine diphosphate}$$

Preliminary evidence (Schwimmer and Makower 1954) indicates that the enzyme responsible for this reaction is present in potatoes.

Relation to Processing and Quality

Potatoes high in sugar taste sweet and have a poor texture after cooking. The poor texture is probably related to the low starch content associated with high sugar content. In the manufacture of potato chips, French fries, and dehydrated potatoes, the sugar content is closely related to the color produced during the processing procedure, and in the case of dehydrated products, to the darkening which may take place during subsequent storage. The source of the yellow to brown color of these products was once attributed to caramelization of the sugars. It has become increasingly clear in the last 15 years that the controlling factor in determining the amount of browning is the reducing rather than the total sugar content. This suggests that the mechanism is not one of caramelization but rather one involving the so-called Maillard or non-enzymatic browning reaction between the aldehyde groups of reducing sugars and the free amino groups of the amino acids and, perhaps to a lesser degree, of the proteins of the potato. An excellent review of the mechanisms of non-enzymatic browning is available (Hodge 1953). Several recent reviews and papers have amply documented the thesis that this Maillard reaction is indeed the principal causative factor in browning (Anderton 1953; Ross 1948; Patton and Pyke 1946; Schwimmer *et al.* 1957B; Habib and Brown 1957).

As a rule, potatoes containing more than two per cent reducing sugars on a dry weight basis are considered to be unacceptable for processing. The correlation between reducing sugar content and browning tendency, although generally good, is by no means perfect. This suggests that there are factors other than reducing sugars and amino acids involved in the browning of processed potato products. These factors may include: organic acids, pH, trace metals such as iron or manganese (Bohart and Carson 1955) and inorganic phosphate (Schwimmer and Olcott 1953). All of these have been found to affect the rate of browning in controlled model non-enzymatic browning systems. In order to secure suitable raw material of low browning tendency, it is general practice to use potatoes which are poor sugar formers and to process potatoes in storage at periods during which they are at a low sugar level and have not sprouted. This may be accomplished by conditioning cold-storage tubers for 2 to 3 weeks at room temperature, or by storing potatoes at 50°F. The latter temperature offers a compromise between excessive sugar formation on the one hand and early sprouting on the other. Sprouting can be prevented by the use of appropriate sprout inhibitors (maleic hydrazide, chloro-iso-

propyl phenylcarbamate, etc.). Successful measures to prevent browning of dehydrated potato products include control of moisture, temperature, and pH, application of sulfur dioxide or sulfites, and treatment with calcium chloride (Simon *et al.* 1955; Schwimmer and Olcott 1953).

NON-STARCH POLYSACCHARIDES

As do all higher plants, potatoes contain non-starch polysaccharides which, for the most part, comprise the cell wall and intercellular cementing substances of the tuber. We may conveniently distinguish among the following: (a) crude fiber, (b) cellulose, (c) pectic substances, (d) hemicellulose, (e) other polysaccharides.

Crude fiber is a generic term which refers to the dry matter of the tuber after removal of all the solubles and most of the starch and nitrogenous constituents. It consists largely of cell wall components including lignin and suberin (a constituent of the peel). According to the earlier literature reviewed by Kröner and Völksen (1950), the crude fiber content of potatoes averages approximately one per cent of the dry weight. Extremes as low as 0.2 per cent and as high as 3.5 per cent have been reported, whereas values as high as five per cent have been reported for the total cell wall dry matter of the tuber. Crude fiber increases during both maturation and post-harvest storage.

Cellulose is present in the supporting membrane of the cell wall and constitutes some 10 to 20 per cent of the non-starch polysaccharide of the potato. Chemically, cellulose is a mixture of high molecular weight polymers consisting of glucose residues combined through β-1,4-linkages. Cellulose is considered to be metabolically inert.

The pectic substances, polymers of galacturonic acid in which the carboxyl groups are more or less methylated, constitute on the average about one per cent of the dry weight of the potato according to the old literature, where they are reported as "total pectin" (Kröner and Völksen 1950). Recent improved analyses based on anhydrouronide content reveal a range of 0.7 to 1.5 per cent (Potter and McComb 1957). The skin contains about ten times more pectin than does the flesh. No correlation has been observed between the pectin and starch contents. Potato slices actively synthesize pectic substances in their cell walls. Application of auxins causes a shift of cell wall composition with a rapid build-up of pectin at the expense of cellulose (Buffel and Carlier 1956). This pectin synthesis is considered to be related to the increased water up-take of potato tissue slices.

The pectic substances of plants are sometimes divided into three categories: (1) protopectin, (2) soluble pectin, and (3) pectic acid. Protopectin is an insoluble, highly polymerized form of pectin associated with

the cell wall structure. It is soluble in acid. Protopectin constitutes 69 to 77 per cent of the total pectic substance of the potato (Bettelheim and Sterling 1955B). Freshly harvested potatoes are relatively high in protopectin but upon storage the protopectin content decreases and the soluble pectin content increases.

The water-soluble pectin appears to arise as a result of the partial depolymerization of protopectin. There is very little soluble pectin in freshly harvested potatoes (Kröner and Völksen 1950). Soluble pectin of stored potatoes contributes 6 to 13 per cent of the total anhydrouronide present in the potato (Bettelheim and Sterling 1955B).

The pectic acid fraction comprises 13 to 25 per cent of the total anhydrouronide of potatoes. In the form of calcium and magnesium salts it is considered to constitute the cementing substance of the middle lamella of the potato tissue. Pure pectic acid contains no methoxyl groups. However, the pectic fraction soluble in alkaline earth sequestering agents (e.g., Calgon), is esterified with methoxyl groups to a certain extent (Bettelheim and Sterling 1955B).

Hemicelluloses are cell wall components made of mixed glycosidic chains containing combinations of glucuronic acid with xylose, and of galacturonic acid with arabinose. It has been reported that about one per cent of the total crude polysaccharide of the potato is present as hemicellulose (LeTourneau 1956A).

Potatoes contain mixed glycosidic polymers made up of varying proportions of arabinose, galactose, and rhamnose (methyl pentose) which can be separated from other polysaccharides (LeTourneau 1956A).

In addition to the above polysaccharides, which are insoluble in hot ethanolic solutions, potatoes contain ethanol-soluble oligosaccharides consisting of fructose and glucose residues. The glucose-containing oligosaccharides appear to be members of the amylose series of low molecular weight which act as naturally occurring primers in the phosphorylase reaction (Schwimmer and Weston 1956; Schwimmer 1957B). The authors are not aware of any studies dealing with potato enzymes responsible for the build-up or degradation of the non-starch polysaccharides.

Relation to Processing and Quality

Although it was suggested at an early date that the cell wall constituents, especially pectin, should play some role in determining texture of cooked potatoes, repeated attempts to obtain significant simple correlations of total pectin content with textural quality or to detect its possible contribution to cell separations have not met with success. However, recent investigations indicate that certain properties of the pectic

substances do indeed contribute to textural quality. Thus it was found that the correlation coefficient of texture with starch content alone was 0.84 (Bettelheim and Sterling 1955A), whereas the multiple correlation coefficient among starch content, total pectin calcium, and total pectinate was 0.96 (Sterling and Bettelheim 1955). It has been suggested that in the development of potato texture, the swelling of the gelatinized starch is the major factor tending to cause rounding off of cells and cell separation. This tendency is opposed by the molecular size and calcium content of the pectic material of the middle lamella and cell wall. The pectic substance of the middle lamella undergoes changes when potatoes are heated at 158°F. (Roberts and Proctor 1955; Shewfelt *et al.* 1955). Addition of calcium salts to the cooking water results in a firmer cooked potato. This may be related to the combination of calcium ion with the free carboxyl groups of the pectic acid. In this connection it may be mentioned that phytic acid present in the potato (Schwimmer 1956B) may affect texture since it could conceivably compete with pectic acid for the available calcium of the tuber.

The crude fiber content is of practical importance in the manufacture of potato starch in which a by-product, consisting largely of crude fiber, is used for feed and as a dusting flour in bakeries.

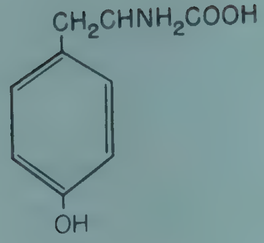
PHENOLIC AND RELATED SUBSTANCES

The phenolic compounds of potatoes are associated with the color of the raw potatoes[2] and are, at least in part, responsible for certain types of discoloration of processed potato products. Chemically we may distinguish the following types of phenolic compounds: (1) lignin, (2) coumarins, (3) anthocyanins and flavones, (4) tannins, (5) monohydric phenols, (6) polyhydric phenols (polyphenols). Fig. 6 shows the structure of some of these compounds.

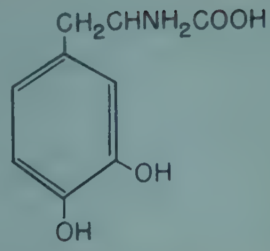
The lignin of the potato is present, if at all, in very low amounts in the vascular tissue of the tuber. The tannins are astringent substances which precipitate from solution in the presence of gelatin. Chemically, tannins are composed of sugars highly esterified with polyphenolic acids (polydepsides). Tannins or their quinones are localized in the suberized tissue of the potato and probably impart the characteristic tan coloration to the skin.

The coumarins, derivatives of the lactone of *o*-hydroxy cinnamic acid, have been claimed to be responsible for the discoloration of cooked potatoes. The coumarin derivatives known as scopoletin and esculetin have

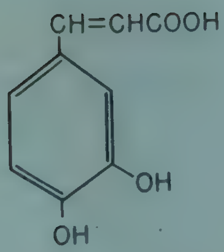
[2] The color of the flesh of the white potato is also partly due to the presence of carotenoids.



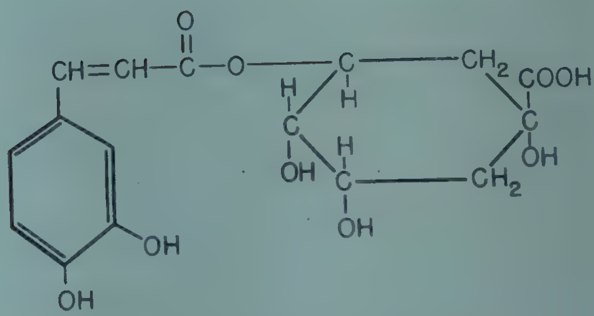
Tyrosine



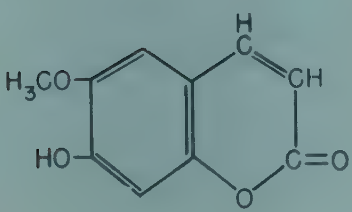
Dihydroxyphenylalanine
(DOPA)



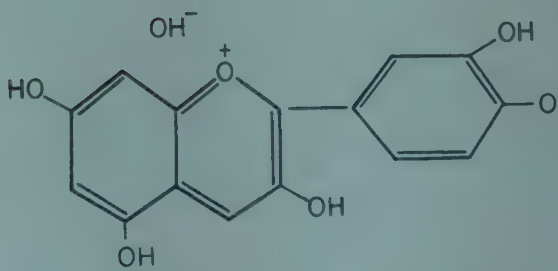
Caffeic Acid



Chlorogenic Acid



Scopoletin



An Anthocyanidine

FIG. 6. STRUCTURES OF SOME OF THE POLYPHENOLS MENTIONED IN THE TEXT

been detected in potatoes (Andrae and Andrae 1949; Bowman and Hanning 1951). The color of the flesh and the skin of certain varieties of potato (e.g., Red McClure) has been ascribed to the presence of anthocyanins and flavones.

Tyrosine, the major monohydric phenol of potatoes, is present in the inner portion of the tuber and constitutes 0.1 to 0.3 per cent of the dry weight of the potato. It crystallizes out from concentrates prepared from ethanolic extracts of potatoes (Schwimmer 1958). Recent investigations

have been more concerned with the polyphenol chlorogenic acid, a caffeic tannin which constitutes 0.025 to 0.150 per cent of the dry weight of the potato tuber (Hunter *et al.* 1957; Clark *et al.* 1957). It is concentrated in a thin layer in the periderm tissue next to the skin. There is about ten times as much chlorogenic acid in the peel as in the flesh of the potato and the concentration in the bud end is about twice that in the stem end. Along with caffeic acid it accumulates over a period of days adjacent to the suberized membrane in freshly sliced potatoes attacked by certain micro-organisms (Johnson and Schaal 1957; Rubin and Askenova 1957; Voros *et al.* 1957; Kuc *et al.* 1956) . Results of recent studies strongly imply that as yet unidentified polyphenols are present in potatoes. Thus the total alcohol extractible polyphenols have been reported to be present in concentrations as high as 0.5 per cent (calculated as chlorogenic acid) of the dry weight of the potato (Hunter *et. al.* 1957). Paper chromatography of these extracts showed the presence of at least ten spots which react as polyphenols.

Tyrosine is oxidized by tyrosinase (polyphenol oxidase), a copper containing enzyme of potatoes, which converts tyrosine into an insoluble brown-to-black polymer known as melanin. Intermediates in this conversion include the dihydric phenol, dihydroxyphenyl alanine (DOPA), dopaquinone, and dopachrome. The latter two compounds are responsible for the red coloration which precedes browning at the freshly cut surface of a potato. Oxidation of chlorogenic acid does not proceed through red-colored intermediates unless an enzyme inhibitor such as 4-chlorocatechol is added to the enzyme reaction system (Waggoner and Dimond 1957). The activity of polyphenol oxidase in the tuber varies considerably according to variety and increases with later date of harvest, during storage, and at the initiation of sprouting.

Other oxidizing enzymes may participate in the oxidation of phenols of the potatoes; these include peroxidase and catalase (Schwimmer 1953).

So far as the authors are aware, no direct evidence is as yet available concerning the synthesis of phenols in potatoes nor of their fate other than conversion under non-physiological conditions to melanins via polyphenol oxidase.

Another function of chlorogenic acid and other polyphenols of potatoes may be their involvement in controlling the metabolism of starch, since it has been found that the compounds are potent inhibitors of starch synthesis by potato phosphorylase (Schwimmer 1958).

Relation to Utilization and Quality

In the normal, uninjured, healthy potato tuber there is no net oxidation of the phenolic substances to form discoloration products. When the

potato tuber is injured by bruising, cutting, or peeling, by disease, or by exposure to toxic vapors, high oxygen tensions, or ionizing radiations, the phenols are rapidly converted to colored melanins. In the pre-peeling industry as well as in other potato processing procedures where there may be a delay between peeling and the next processing step, it is imperative to prevent or counteract the action of the polyphenol oxidase in forming undesirable colored polymers. The following approaches have been used or proposed to prevent this type of discoloration:

(1) Conditions which destroy or slow the action of the enzyme, e.g., heat, acid, low temperatures, organic solvents, etc.
(2) Substances which compete with polyphenol substrates for the active site on the enzyme molecule (competitive inhibitors), e.g., benzoic acid, hydrogen ion.
(3) Substances which combine the enzyme-bound copper, e.g., diethyldithiocarbamate, 8-hydroxy quinoline, perhaps citric acid, thiol compounds, thiourea.
(4) Substances which reconvert the quinones (formed by the action of the enzyme) to the original polyphenols, thus preventing the subsequent polymerization to colored products, e.g., ascorbic acid, sulfite, and other reducing agents.
(5) Substances which combine with the substrate to yield substances not attacked by the enzyme, e.g., borate, titanate.
(6) Substances which modify the melanin polymer to give light colored substances, e.g., 4-chlororesorcinol and glutathione.
(7) Non-reducing substances which can create a reducing environment at sliced potato surfaces or in homogenates and thus prevent color formation, e.g., adenosine triphosphate.
(8) Leaching out of phenols with organic solvents.

The most effective and practical combination in use today in the preparation of pre-peeled potatoes consists of a combination of controlling acidity with citric acid and the application of sulfite (Mullins *et al.* 1953).

It has been found that the flesh of certain lots of potatoes turns to grey or black after cooking. The blackening, referred to as "after-cooking discoloration," occurs under the skin in the stem end of the tuber. It will not occur at pH values below 4 to 5. The color disappears when the pH of the potato is lowered to this level. Since the color of the end-product of enzyme action does not behave this way, it is quite probable that this darkening is not related to enzymatic browning. It occurs more frequently in lots of potatoes grown on soils low in potassium and high in nitrogen. There is no correlation between the appearance of this type of discoloration and amount and distribution of the polyphenols of the

potatoes (Hunter *et al.* 1957), although the latter have been implicated in this phenomenon. A review of investigations of the phenomenon is available (Yanovsky 1955). According to the most recent theories, this darkening occurs as the result of the interaction of ferrous salts of the potato (or derived from the cooking vessel) with chlorogenic and caffeic acids to form complexes which are then easily oxidized by the oxygen of the air to black polymers (Kiermeir and Rickerl 1955). Thus the degree of darkening would depend upon the amount and availability of ferrous iron at the site of the discoloration, since the polyphenols would be present in excess.

This type of discoloration can be delayed, prevented, or in some cases reversed, by treating the peeled tubers with the following chemicals: certain acids, stannous oxalate (Smith *et al.* 1942), sodium bisulfite, sulfur dioxide (Smith 1958), pyrophosphate, borate (Juul 1949), or sequestering agents (Greig and Smith 1955; Smith 1958). Smith and Muneta (1954) were able to reduce the susceptibility of potatoes to after-cooking darkening by foliar application of sequestering or chelating agents to the plants before harvest.

CHLOROPHYLL

The green color which appears in the area immediately beneath the skin of a potato tuber exposed to visible light over a period of several days has been shown to be due to the presence of chlorophyll (Larsen 1949). The greening never extends more than one-eighth inch below the surface of the tuber and the amount of chlorophyll formed very seldom exceeds one mg. per 100 $cm.^2$. The temperature optimum for chlorophyll formation is about 68°F. Below 40°F., very little greening occurs. At the optimum temperature there is a proportionality between the rate of chlorophyll formation and the light intensity up to five foot candles, but at low temperatures increased light intensity has very little effect on greening rate. Neither humidity, time of harvest, nor storage influence the rate of greening. The economic importance of potato greening lies in the lack of marketability of such potatoes, in part due to the association of greened potatoes with bitter taste and to the suspicion of poisonous substances being present (see section on solanine). Green color occasionally is noted in some processed products where the depth of peeling has not been sufficient to remove the surface layers completely.

The best method for preventing greening is, of course, to keep the potatoes away from visible light. The following have also been found to reduce the rate of chlorophyll formation: use of blue or green screens; treatment with sulfite and acid; treatment with chemicals which have

been found to prevent chlorophyll formation in other plants (*o*-methyl threonine, triamino azole); and ionizing radiations. Chemical sprout inhibitors have not so far been found to be effective in preventing greening (Schwimmer and Weston 1958).

SOLANINE

Solanine is the term applied to the steroidal alkaloid fraction of potatoes soluble in acidified alcohol and insoluble in slightly alkaline aqueous solution, the aglycone of which is solanidine (see Fig. 7). According to recent investigations, this fraction contains free solanidine and a mixture of glycosides. Of the latter the most important is α-chaconine, in which the sugar sequence is glucose-rhamnose-rhamnose. The sugar sequences of other solanidine glycosides also present in potatoes are as follows: β-chaconine, glucose-rhamnose; γ-chaconine, glucose; α-solanine, galactose-glucose-rhamnose; β-solanine, galactose-glucose; γ-solanine, galactose (Paseshnichenko and Guseye 1956).

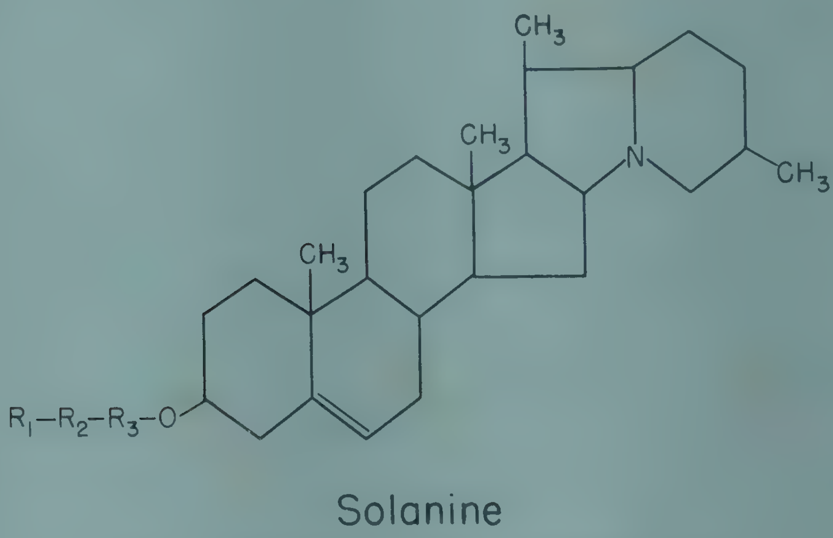


FIG. 7. STRUCTURE OF THE GLYCOSIDE SOLANINE

R_1, R_2, and R_3 represent sugars attached to the solanidine moiety.

Kröner and Völksen (1950) and Burton (1948) have reviewed the early literature on solanine. Solanine, as the total alkaloid fraction, is present in the normal whole tuber to the extent of 0.01 to 0.10 per cent of the dry weight. There is at least twice as much in the peel as in the flesh and it seems to be concentrated in the vicinity of the eyes. Exposure of freshly harvested potato tubers to ultraviolet light causes a several-fold increase in the solanine content. This indicates that development of solanine and of chlorophyll are not directly related phenomena since the development

of the latter is responsive to visible light, particularly the red end of the spectrum. Sprouts contain much more solanine than the tubers; values as high as 1.7 per cent solanine have been reported for sprouts exposed to ultraviolet light.

Since solanine is a poisonous alkaloid, its presence in increased amounts in the potato tuber has, in the past, been considered to be a health hazard. Potatoes containing more than 0.1 per cent solanine are considered to be unfit for human consumption. However, most of the authenticated reports of solanine poisoning are in connection with the use of sprouts as edible shoots.

VITAMINS

Although the nutritional significance of potatoes has been commonly equated with their caloric value, modern research is developing a picture of the potato as a good source of many of the vitamins. The following have been detected in nutritionally significant amounts: vitamin A (as carotene); thiamin; riboflavin; ascorbic acid; niacin; pyridoxin; vitamin K; biotin; inositol; and pantothenic acid. By far the greatest attention has been devoted to ascorbic acid.

Potatoes are an important dietary source of ascorbic acid, particularly among low income families and in European countries where *per capita* consumption of potatoes is high. The amount of ascorbic acid in potatoes as reported in the literature varies from about 10 to 40 mg. per 100 gm. of fresh tubers (Kröner and Völksen 1950). Watt and Merrill (1950) give 17 mg. per 100 gm. as the year round average for the edible portion of potatoes. The vitamin is concentrated in the vascular zone and in the bud end of the tuber (Paech 1938). Relatively high concentrations of ascorbic acid have been reported to be associated with the following: advanced maturity; late harvesting date; large tubers; certain diseases, e.g., leaf roll; treatment of tubers with ethylene chlorohydrin; high altitude of planting site; initiation of sprouting (particularly near the eyes). The question of the influences of manuring, fertilizers and variety is still unsettled. Upon storage of the freshly harvested potato there is an initial rapid loss of ascorbic acid followed by a slow decrease (Barker and Mapson 1952). Over several months, more than half of the original ascorbic acid in the potato may disappear. This loss is more rapid and more severe the lower the storage temperature. Freezing the tubers conserves the ascorbic acid, but upon subsequent thawing the loss is extremely rapid and extensive. Blight and storage in CO_2 atmospheres also lead to increased losses of ascorbic acid (Kröner and Völksen 1950).

Recent interest in ascorbic acid has been broadened to include its conversion products, dehydroascorbic acid (DHA), which exhibits anti-

scorbutic activity, and diketogulonic acid (DKGA), which does not. Both of the latter compounds have been reported to be present in freshly harvested potatoes in concentrations roughly 10 per cent that of reduced ascorbic acid (AA) (Leichsenring *et al.* 1957). Stored potatoes lose DHA faster than the reduced forms; after several months storage its contribution to total ascorbic acid is less than one per cent. Since there is an actual loss of DKGA, losses in AA and DHA cannot be calculated from the accumulation of DKGA.

About half of the reduced ascorbic acid of the fresh tuber is present in a bound form which can be liberated by exposing the tuber to the high temperatures of boiling, baking, roasting, etc. That is, the total extractible AA increases during such treatments. Bound AA decreases during storage.

Not much is known about the enzymes concerned with ascorbic acid metabolism in potatoes. Although it has been considered that there exists a specific ascorbic acid oxidase in potatoes, it is likely that the oxidation to DHA at the surface of a freshly peeled potato or in freshly minced potatoes occurs by reaction with quinones formed from the action of polyphenoloxidase.

It has been shown that there is very little loss of AA due to peeling, but the losses are increased if the tuber is subdivided to any great extent due to the above mentioned action of polyphenoloxidase. Where there is a heating step in the process, as mentioned above, there will be an initial apparent increase. Exposure to extreme temperatures such as occur in baking and pressure cooking tend to oppose this increase. Loss of AA occurs in cooked potatoes when they are stored at refrigerator temperatures for an appreciable length of time, e.g., 24 hours (Leichsenring *et al.* 1957). Part of this loss seems to be due to conversion to DHA. Freshly cooked potatoes contain very little, if any, more DHA than the raw potato. Cooking does cause an increase in the DKGA content which is not further enhanced upon storage in the refrigerator.

Such data as are available on the ascorbic acid content of potato products indicate that losses that occur during processing are highly variable and may be quite large. Watt and Merrill (1950) give 23 mg. per 100 gm. as the AA content of dehydrated potatoes. On a fresh weight basis this would correspond to approximately 6 mg. per 100 gm. Olson and Harrington (1955) report a loss of 21 per cent in converting fresh potatoes to potato granules by the add-back process. The rate of loss of ascorbic acid from air-packed potato granules during storage is accelerated by high moisture content; packing the product in an inert atmosphere greatly retards this loss (Kissmeyer-Nielsen 1956).

Other vitamins have been found to be present in potatoes in the follow-

ing concentrations as mg. per 100 gm. of potato: thiamin, 0.05 to 0.12; carotene, 0.01 to 0.06; riboflavin, 0.01 to 0.06; niacin, 0.4 to 1.2; vitamin K, 0.10. Storage causes considerable loss in thiamin content. A special problem of the relation of thiamin to preparation of potatoes for processing lies in the sensitivity of thiamin to sulfite. Thus it has been reported (Anderson *et al.* 1954) that sulfiting of whole potatoes and potatoes prepared for French fries results in losses of 12 per cent and 40 per cent, respectively.

The yellowish tinge in the flesh of potatoes is attributed to carotenoids, of which a portion, one-tenth to one-half, according to the findings of Caldwell *et al.* (1945), consists of carotene (provitamin A). Three yellow-fleshed varieties of potatoes contained 6 to 10 times as much carotenoid as the white-fleshed varieties.

It has been reported that two-thirds of the riboflavin, niacin, and pantothenic acid are present in the peel (Hansen *et al.* 1957).

NITROGEN

The total nitrogen content of potatoes ranges from one to two per cent of the dry weight. About 90 per cent is soluble in the usual aqueous solvents, the insoluble remainder being associated with the skin and outer cortex. Very little nitrogen is present in the vascular areas, but nitrogen content increases with increasing distance from this region toward the center and toward the peel. There is thus an inverse relationship between the distribution of starch and of nitrogen. It is generally agreed that variations in environmental factors exert a greater influence on nitrogen content than does variety except that early varieties tend to contain more nitrogen than do late varieties. High nitrogen content has been found to be associated with advanced maturity, manuring, potassium deficiency, and certain virus diseases. The bulk of the evidence suggests that very little change in total nitrogen occurs during post-harvest storage prior to sprouting.

Protein

About $^1/_3$ to $^1/_2$ of the total nitrogen is present as protein. The proportion of protein is higher in immature than in mature tubers. In tubers approaching termination of dormancy, protein tends to disappear from the pith (Tagawa and Okazawa 1955). The protein content of the area around the eyes is increased in leaf roll (McAnelly *et al.* 1956).

There are, of course, quite a number of entities comprising the protein fraction of potatoes. However, it is customary to distinguish among various fractions on the basis of solubility. Thus it was early recognized that there is present in potatoes a globulin, tuberin, which can be extracted

by ten per cent NaCl. This fraction was found later to consist of at least two proteins (Groot *et al.* 1947). About one-half of the crude protein is extractible by water and only about one-half of this is soluble in slightly acid media (Levitt 1954). The soluble fraction, or albumin, seems to be a mucoprotein.

Deposits of cubic protein crystals, formerly thought to be associated with virus disease, are occasionally found in the eyes of the tuber (Fetodina 1957).

Amino Acids

The bulk of the non-protein fraction, comprising up to two-thirds of the total nitrogen, is present as free amino acids (Neuberger and Sanger 1942). The changes in free amino acid content which occur during storage are rather small except for a marked decrease of many of the components when the tubers are conditioned at room temperature after being held at lower temperatures (Habib and Brown 1957). Asparagine and glutamine are present in approximately equal amounts and together comprise about one-half of the total amino acids. Glutamine is associated with the inner layer of the tuber and asparagine with the outer layers. Chromatographic analysis has revealed the presence of almost all of the 20-odd classical amino acids. The following amino acids have also been detected: γ-amino butyric acid (about 5 per cent of the total), α-amino butyric acid, β-alanine, and methionine sulfoxide (Dent *et al.* 1947; Steward *et al.* 1957; LeTourneau 1956B). In contrast to the amino acid composition of the proteins of the potato, the free amino acid pattern is affected by storage, nutrition of the plant, and treatment with such chemicals as ethylene chlorohydrin (Satarova 1955; Mulder 1956).

Other Nitrogenous Components

Compounds which contain peptide bonds but are shorter than proteins have been found in potatoes. These include glutathione, proteoses, peptones, and possibly fragments of intermediate chain length. Also reported present are: choline, acetyl choline, trigonelline, cadaverine, adenine, hypoxanthine, allantoin, and nitrate (see Kröner and Völksen 1950).

Enzymes of Nitrogen Metabolism

The free amino acids have been shown to serve as a source or reservoir for protein synthesis (Steward *et al.* 1940). The free amino acids, with the exception of glutamine and asparagine, tend to disappear. There is also present significant protein hydrolyzing activity (Niemann 1957). This proteinase is similar to certain other plant proteinases such as papain and ficin. Polypeptides capable of inhibiting the action of proteinases

have been isolated in crystalline form (Sohonie and Ambe 1955). Other enzymes of nitrogen metabolism have been reviewed by Schwimmer (1953). It is quite likely that further research will reveal a host of enzymes responsible for the appearance of the many nitrogen constituents mentioned above.

Relation to Processing

The interaction of the free amino acids with the reducing groups in the potato has already been discussed in the section on sugars. According to Kröner and Völksen (1950), it has been considered feasible in Europe to recover the protein and amino acids present in the wash water from the manufacture of potato starch. Recovery procedures involving concentration, coagulation, and foaming have been proposed. The nutritive value of the protein of the potato (including the free amino acids) is considered to be at least equal to that of any other vegetable protein. Distillery wastes containing almost all of the nitrogen of the original potatoes are considered to be an excellent cattle feed. Since potato protein reacts serologically, a test based on this serological reaction has been developed for the detection of potato in salads and baked goods (Kröner and Völksen 1950). Tyrosine has been considered to react with iron and oxygen to yield off-color potato starch and after cooking discoloration (Mulder 1956).

LIPIDS AND ORGANIC ACIDS

Surveys of the literature (e.g., Kröner and Völksen 1950; Lampitt and Goldenberg 1940) indicate that the average fat content (ether-extractible matter) of the potato is in the neighborhood of 0.10 per cent on a fresh weight basis, with a range of about 0.02 to 0.2 per cent.[3] Hendel *et al.* (1951) give evidence that in potatoes, as in various other plant materials, a portion of the lipids may be bound to other constituents. Exhaustive extraction of potato granules with petroleum ether yielded 0.15 per cent fat (dry basis), but further extraction of the potato residue with ethanol gave an additional 0.20 per cent of petroleum ether-soluble material. Early potatoes contain more lipids than late varieties. The concentration of lipids is greatest in the periderm and least in the vascular storage parenchyma and pith. The fat from the outer layers of the tuber is reported to be a brown, viscous oil, while that from the inner part is light colored and butterlike in consistency.

König (1920) gives the composition of potato lipids as 76.17 per cent C; 11.85 per cent H; 11.98 per cent O; and the unsaponifiable matter as

[3] One value of 0.96 per cent has been reported but this appears to be high and out of line with the rest of the values in the literature.

10.89 per cent. Various workers have reported the following fatty acids to be present: myristic, palmitic, oleic, linoleic, and linolenic. Ceryl alcohol, phosphatide, sitosterol and stigmasterol have also been found (Schwartz and Wall 1955). Highlands *et al.* (1954) extracted approximately 0.02 per cent fat from air-dried and from vacuum-dried potatoes with petroleum ether. The fatty acids in this material consisted of about 40 per cent linoleic, 30 per cent linolenic, 5 per cent oleic, and 25 per cent saturated acids. The iodine number was 158 to 160, and the stability, as measured by the increase in peroxide number during incubation at 148°F., was about the same as that of olive oil. From these observations, one would expect potato fat to be relatively susceptible to oxidative deterioration, a fact that has been confirmed by experience with potato flour and potato granules (Burton 1949; Hendel *et al.* 1951).

Not much is known concerning the enzymes involved in fat metabolism in the potato, although the existence of lipoxidase has been reported (Sullman 1943; Sumner 1943).

Beside the amino and fatty acids, which have been discussed, the following organic acids have been reported to be present in potatoes: lactic, succinic, oxalic, malic, tartaric, citric, isocitric, ascorbic, aconitic, α-ketoglutaric, phytic, caffeic, quinic, and chlorogenic (Kröner and Völksen 1950; Schwimmer 1956B; Barker and Mapson 1953; Hunter *et al.* 1957).

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N. R. Thompson

Potato Varieties

Many varieties of potatoes are grown in North America each year. However, a few varieties account for most of the potatoes produced. These differ in time of maturity, yield, appearance, disease resistance, market, and cooking quality. Often an identifiable characteristic such as skin color or shape of tuber may account for the popularity of a variety. Resistance to a disease or insect may be of particular interest in a given area. Some varieties have a narrow range of adaptability and are suited to a particular environment. Many are too new to have been widely tested.

The problem of selecting the best potato requires a knowledge of potato varieties. Also, one must understand the environment, the purpose for which the potato is to be used and the requirements it must meet.

Potato varieties have fluctuated in numbers and popularity as the potato industry has changed over the years. In the early colonial days marketing was not a problem. Most of the population was gainfully employed on farms, therefore, most of the potato crop was consumed where it was grown. Also, a large proportion of the crop consisted of varieties too poor in quality for human consumption and was used as livestock feed.

In the middle of the 19th Century late blight, *Phytophthora infestans* (Mont.) (de Bary) caused great destruction for a number of seasons in North America as well as Europe. This late blight had far-reaching effects upon the potato industry. It stimulated efforts to breed new varieties that could withstand its ravages. Though the effort failed, the introduction of large numbers of new varieties resulted in some with very high cooking quality. The Garnet Chili, Early Rose, Burbank, Peach Blow, Early Ohio, Triumph and Rural New Yorker No. 2 enjoyed wide popularity for many years.

The relatively stabilized variety situation of today and the caution with which new varieties are introduced make it difficult to imagine the enthusiasm for new varieties that existed before the turn of the present century. Most potato growers tried out several each year. The business of introduction and dissemination of new varieties grew rapidly. Seed catalogs offered many varieties, often with extravagant claims for high yields, good cooking quality and resistance to disease. The high prices paid for

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tubers led unscrupulous dealers to offer old potatoes under new names. In every district there were local names for potatoes which were known nowhere else. But what was worse, similar names were used for potatoes of extremely different qualities. Variety nomenclature became so confused that names had no value.

DEFINITION OF A VARIETY

What is a potato variety? Each variety is the progeny of a single potato plant, which arose from a single seed. Occasionally visible changes, which are maintained by asexual or vegetative propagation, give rise to new varieties, i.e. the Russet Rural was found in Rural New Yorker No. 2. The ability to consistently reproduce the original or a specific alteration of the original is the main characteristic of a variety.

CLASSIFICATION OF VARIETIES

To promote some order to the potato industry, several attempts were made to classify varieties. Kohler (1909) was one of the first American workers to present a classification. Others were Ballou (1910), Milward (1912) and Fitch (1914). However, it remained for Stuart (1915) to bring order out of chaos. After studying the growth habits of a large collection of potatoes in Maine, he was able to group them by tuber characteristics. Twelve groups were described, and all similar varieties and their synonyms were placed in a group. Each group was designated by its most widespread and popular variety. At the same time seed certification agencies were cooperating to utilize a common nomenclature for varieties. While synonyms and trade names are still used to some extent, variety names are relatively stable today.

The evolution of potato production from a plot on each farm to a specialized crop changed the attitude of growers to potato varieties. Concentration of potato production led to a demand for earlier maturing, disease resistant varieties with better market appeal. In 1929 the potato-breeding program of the United States Department of Agriculture was reorganized as a National Potato Breeding Program cooperating with state experiment stations. As a result of this stimulus, many new varieties have been released through the combined efforts of federal and state programs. Many of the older varieties were quickly replaced by the newer introductions. These newer introductions were not as well suited to grouping as the varieties classified by Stuart.

Clark and Lombard (1946) prepared a description and key to American potato varieties based on plant, flower, tuber and sprout characteristics. They included 39 varieties with brief notes on 14 varieties of lesser

importance. Many of the varieties described in 1946 are now of minor importance and new ones must be added to the list.

In addition to plant characteristics, other means of identifying varieties have been established. Whitehead *et al.* (1953) point out that McIntosh, studying some of the rarer compounds in the potato, was able to utilize chemical tests to group varieties and separate types. In other European countries, ultraviolet ray fluorescence has been successfully used to distinguish varieties. Some varieties give a characteristic fluorescence.

ORIGIN OF VARIETIES

The first potato varieties developed in North America resulted from seed in chance seed balls (assumed to be self-fertilized). Varieties of importance that originated in this manner are Burbank, Rural New Yorker and probably Irish Cobbler. Later workers practiced hybridization (cross-pollination). Several lasting potato varieties were produced. The most popular were Green Mountain and Triumph.

Fig. 8. Triumph

Current potato varieties are derived chiefly from cross-pollination. The early breeders cross-pollinated the best varieties to produce Katahdin, Chippewa and Pontiac. Later in the search for disease resistance, species other than S. *tuberosum* have been introduced. Such varieties as

Kennebec, Merrimack, Delus and Saco have derived blight resistance, through the so-called "German W races," from S. *demissum.*

Several varieties have arisen through "sports" or mutations. These usually differ from the original clone in color of the tubers, stem, flowers, shape of leaves, degree of pubescence and in the structure of the skin. Asseyeva (1927) suggested, and was able to demonstrate, that such variations were chimeras. They are usually a physical characteristic readily noticed in the tuber (Fig. 9). Changes in skin color produced the Red Warba, the Red Pontiac and the White Pontiac, while changes in color and texture of the skin produced the Russet Sebago and Russet Rural. Mutations are not always constant.

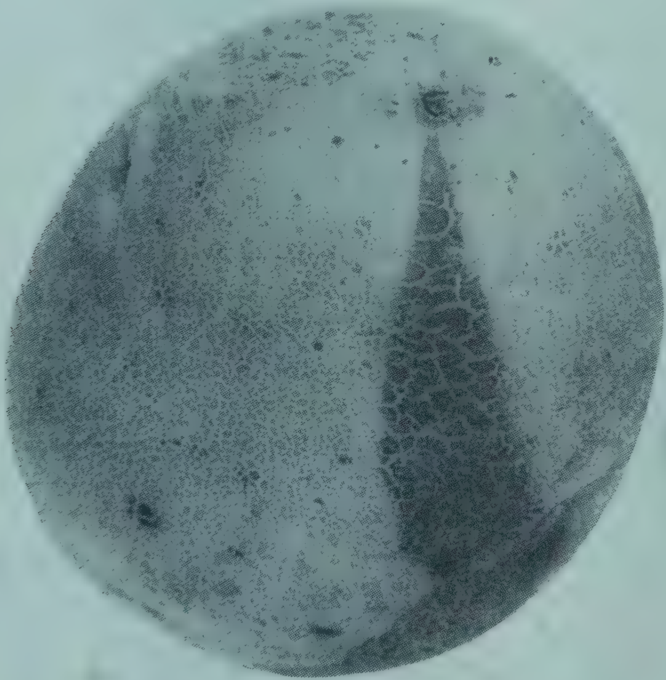

FIG. 9. A COLOR MUTATION IN THE TAWA VARIETY

Webster and Rieman (1949) reported a clonal line of Sebago potatoes which exhibited a high degree of instability. Two abnormal vine characteristics and three different types of tuber russeting have been observed. These can be propagated vegetatively. The abnormal vine type produces double russeting of the tubers. This abnormal vine type resembles to some extent the symptoms of a potato infected with the virus which causes leaf roll. Reversion of the abnormal vine type to normal occurs frequently and is always accompanied by a change to single russeting of the tubers. These changes are of academic interest but have not produced new varieties.

DEGENERATION

Of the more than 350 varieties released in the last half of the 19th century, only a few of those best adapted have remained in commercial production. As the length of time a variety had been in cultivation increased, the yield and vigor of the variety appeared to decrease. Careful selection of the best appearing tubers for seed purposes did little to delay the procedure. Early theories attributed this degeneration or "running-out" of the potato to senescense. More than anything else, this appears to have been the reason for the decline and eventual disappearance of many potato varieties. Some of the older varieties possessed good yielding ability, eye appeal and attractive market appearance. This degeneration, for no apparent reason, soon caused new varieties to decrease in yield and vigor. It was thought to be the result of continuous asexual or vegetative propagation which weakened the stamina of the variety. The only known remedy was to replace the variety by one raised from true seed. Such theories stimulated the release of many new varieties in the last half of the 19th century. Every few years there were highly reputed new varieties from which to choose, and degeneration caused little concern.

When the knowledge of disease became widespread, it was generally accepted that viruses and not vegetative propagation were the cause of degeneration. Most investigators have discarded the theory of senescense. Bushnell (1928) studying the problems of seed production in hotter climates reported records of some very old varieties. One, Long John, which had been grown continually for ninety years, still maintained high vigor and yield capabilities. In contrast, some new varieties susceptible to viruses have degenerated in a few years. The degeneration of potatoes caused by viruses could come about by (1) intensification of the virus within the plants, (2) an increase of the number of plants infected, (3) a combination of both, (4) infection with more than one virus. However, Rieman *et al.* (1951) presented evidence which indicates that not all degeneration commonly observed is necessarily of virus origin. They show that variations within a variety contribute to loss of vigor. It was suggested that clonal selection to eliminate deleterious variants of genetic origin was a valuable tool to maintain varieties at high levels of production.

DESCRIPTION

Listings of the varieties in the Certification Seed Potato Reports of the United States Department of Agriculture change from year to year. There is less than 100 acres of seed of half the varieties currently listed. A dozen varieties account for the bulk of the potatoes produced.

To classify and describe each of the varieties available from year to year would be a big undertaking. Newer varieties differ little in shape and

color of tubers. They differ widely in disease resistance, adaptability and dry matter content. Any simple grouping does not seem practical. A detailed description of vine type, flower and tubers would be impractical because of the short duration of some varieties and the fact that more new ones will be available each year.

Changing trends in production result in fewer people being interested in the detailed study of variety characteristics. More people are interested in the end product—the tuber. The author feels that a description of maturity, tuber characteristics, adaptation and usefulness will better supply the needs of most interested parties. References are supplied for the more interested so they may be able to find the details they desire. Descriptions are confined to some of the old varieties still popular and the newer varieties that contribute to most of the present production. Many varieties have been omitted because only a few acres are grown in isolated areas. Some of the modern varieties have failed to fill the requirements of commercial production and are falling or have fallen by the wayside. Others are too new to have been adequately tested (Table 6).

Katahdin

Maturity late or medium late; tubers large, elliptical to round, medium in thickness; skin smooth, dark creamy buff (considered white in commercial trade); eyes shallow.

The Katahdin variety was released in 1932 by the United States Department of Agriculture. It possesses wide adaptability. The foliage is large and spreading with thick stems that stand upright, making cultivation and spraying easy. It is resistant to mild mosaic, net necrosis and brown rot. It is immune from wart; it does not become infected with virus leaf roll as readily as most varieties. It is susceptible to late blight and common scab.

The tuber set is average and regardless of the season it consistently produces a high percentage of smooth, number one size tubers which are easily removed from the stolons. Under adverse growing conditions it rarely produces misshapen tubers. The tubers injure easily and care should be exercised at harvest time to prevent bruising. The tubers set high on the stem and may result in greened tubers if hilling is not practiced. The eyes, in addition to being shallow, are few in number. If seed is to be cut for planting, larger amounts of seed may be required to assure at least one eye in each seed piece. Under normal storage conditions the keeping quality is good. The cooking quality is fair to good. It exhibits some tendency to discolor after cooking. The cooked tubers may usually be identified by their off-white color. Specific gravity of the tubers is medium. However, there is considerable variability within a given lot and

TABLE 6

DESCRIPTION OF VARIETIES

Variety	Year Released	Originating Agency	Maturity[1]	Tuber Shape	Depth[2] of Eye	Skin Color	Specific Gravity	Disease Resistance	Process Rating
Antigo	1955	Wisconsin	M	Round		White	Medium	Scab	Fair
Boone	1955	Dept. Agr.[3] and N. Carolina	L	Oblong	S	White	Medium	Late blight	Poor
Cherokee	1951	Iowa Indiana and Dept. Agr.[3]	M-E	Round	M	White	High	Late blight, scab, net necrosis	Good
Dazoc	1953	Nebraska	E	Round	S	Red	Medium	. . . .	Poor
Early Gem	1953	Dept. Agr.[3] Idaho and North Dakota	E	Long, elliptical	S	Russet	Low	Scab	Poor
Green Mountain	1878	Vermont	L	Oblong, flattened	M	White	High	. . . .	Poor
Irish Cobbler	. . . .	. . . .	E	Round with blunt ends	D	White	High	Mild mosaic	Good
Katahdin	1932	Dept. Agr.[3]	M-L	Round	S	White	Medium	Mild mosaic, net necrosis	Good
Kennebec	1948	Dept. Agr.[3]	L	Elliptical	S	White	High	Late blight, net necrosis	Excellent
Keswick	. . . .	Canada	M	Elliptical, oblong	M	White	High	Late blight	Excellent
LaSoda	1947	Louisiana	E	Oblong, round	M	Pink	Medium	. . . .	Poor

Merrimack	1954	Dept. Agr.[3] and New Hampshire	L	Round	S	White	High	Late blight, ring rot, net necrosis	Excellent
Ontario	1946	Dept. Agr.[3] and New York	L	Oblong	S	White	Medium	Scab, late blight	Poor
Plymouth	1955	Dept. Agr.[3] and North Carolina	M	Oblong	S	White	Medium	Late blight, scab	Fair
Pontiac	1938	Dept. Agr.[3] and Michigan	L	Round-oblong	M-S	Red	Medium	Net necrosis	Poor
Progress	1948	Nebraska	E	Round	S	Red	Medium	Some scab resistance	Poor
Pungo	1950	Virginia and Dept. Agr.[3]	E	Elliptical, round	M	White	High	Late blight	Fair
Rural New Yorker	1897	New York	L	Oval	S	White	High	...	Excellent
Russet Burbank	...	...	L	Cylindrical	S	Russet	High	Scab	Excellent
Russet Rural	1903	Michigan	L	Oval, flattened	S	Russet	High	Scab	Excellent
Russet Sebago	...	Wisconsin	L	Round, elliptical	S	Russet	Medium	Scab, field resistance to late blight	Fair
Saco	1954	Dept. Agr.[3] and Maine	L	Short, round	M	White	High	Late blight, Xi, A, net necrosis	Excellent
Sebago	1938	Dept. Agr.[3]	L	Round, elliptical	S	White	Medium	Field resistance to late blight	Fair
Triumph	1878	Connecticut	E	Round, thick	M	Red	Medium-low	...	Poor

[1] Maturity: E—Early, M—Medium, L—Late.
[2] Depth of Eye: S—Shallow, M—Medium, D—Deep.
[3] United States Department of Agriculture.

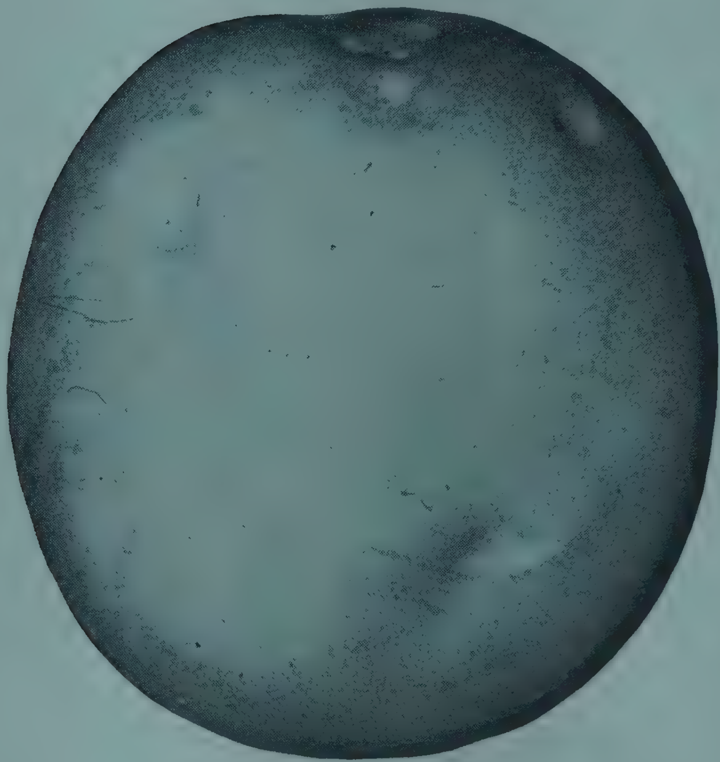

FIG. 10. KATAHDIN

even within a hill. Katahdin is satisfactory for the manufacture of potato chips both at harvest and after conditioning. The fried slice may not be a uniform color but may vary in intensity from one end to the other. The popularity of this variety is due to its consistent production of a smooth, marketable crop of potatoes.

Russet Burbank

Maturity late; tubers long, cylindrical or slightly flattened, skin russeted, heavily netted; eyes well distributed, shallow and numerous; flesh white.

Russet Burbank is one of the older varieties. Its origin is unknown. This variety is extensively grown in the states of the Pacific Northwest and in Maine. The plants are medium in size. They are susceptible to most virus diseases, late blight and particularly susceptible to fusarium and verticillium wilts. The foliage is quite succulent and requires a consistent spray program to control insects. The tubers possess some resistance to common scab. It sets a large number of tubers per plant and therefore requires proper spacing of the seed piece relative to the productivity of the soil. It responds well to irrigation giving best results from moderate

amounts of water consistently applied throughout its growing season. Under unfavorable conditions it produces many small and off-type tubers—dumbells and knobs from second growth. When grown where best adapted, it produces tubers high in dry matter which are excellent for baking and for the manufacture of potato granules and potato flakes. It makes desirable long type French fry slices and is used for potato chip manufacture in some areas. This variety has been promoted as the "Idaho Baker" and when produced in Idaho has commanded a premium as a baking potato.

Red Pontiac

Maturity late; tubers large, oblong to round, blunted ends; skin smooth or sometimes netted, uniformly colored, red; eyes medium in depth, red; flesh white.

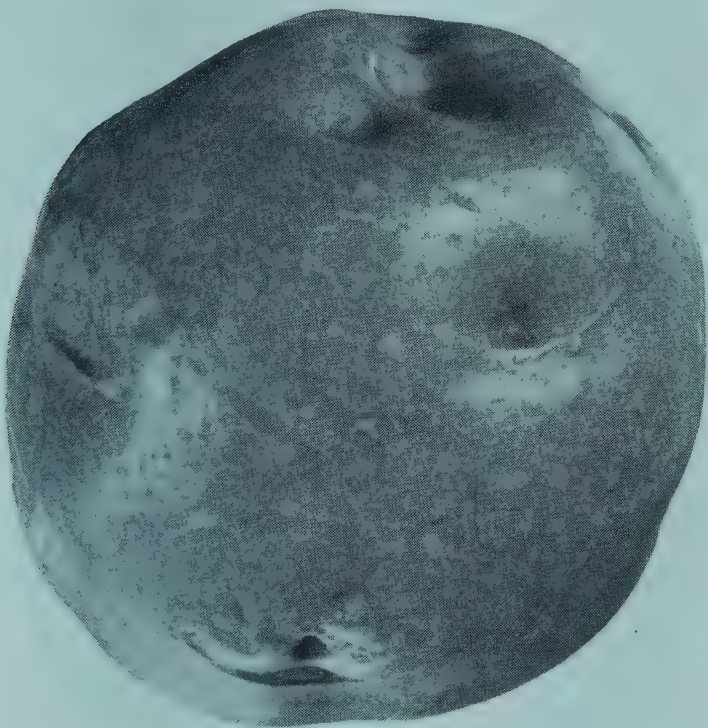

Fig. 11. Red Pontiac

Red Pontiac is a red mutant of the Pontiac variety originating in 1948. The foliage is heavy and requires thorough spraying to control hopper burn. It is not markedly resistant to common scab, late blight or virus diseases. Where adapted it produces high yields of dark red tubers. The tubers set early and in some sections it is used as an early potato. The

tubers set close to the surface of the ground and are quite subject to "sun-green."

In Michigan and Ohio, Red Pontiac has shown some drought resistance and is free from hollow heart and misshapen tubers. Caution must be exercised to avoid air checks at harvest time. The tubers have a short dormant period. The cooked potato resists after cooking darkening and can usually be depended on to supply a very white boiled potato. It tends to produce tubers of low specific gravity. This variety has not found favor for the manufacture of potato chips or most other forms of processing. Because of tuber size it makes a desirable long type French fry slice which cooks to a golden brown. The golden brown color may be attained while the center of the slice remains a soft pleasing texture.

Irish Cobbler

Maturity early; tubers large to medium in size, roundish with blunt ends, the stem end often notched rather deeply, giving a shouldered appearance to the tuber; skin smooth, creamy white; eyes shallow to rather deep, particularly in the bud eye cluster; flesh white.

Fig. 12. Irish Cobbler

Irish Cobbler is one of the old potato varieties. Its origin is unknown. The foliage is erect and medium in size. It is resistant to mild mosaic but susceptible to most other virus diseases, scab and late blight. It is popular because of its early maturity and wide adaptation. It is grown

in nearly every state. The eyes are numerous and cut seed produces a good stand. The tubers have a long dormant period and keep well in storage. Specific gravity is medium to high and the cooking quality usually is good. When boiled, Irish Cobbler tubers may be faulted occasionally for sloughing. It makes good potato chips and is widely used in the late summer and early fall months. Because of its shape and deep apical end there is more than average peeling loss. This variety is very popular for the home garden.

Kennebec

Maturity late, although it is considered medium late in some states. Tubers large, elliptical to oblong, medium thick; eyes shallow; skin smooth, creamy buff; flesh white.

Fig. 13. Kennebec

The Kennebec variety was released in 1948 by the United States Department of Agriculture. It is a fast growing, high yielding variety with wide adaptability. It is resistant to the common race of late blight and to net necrosis caused by virus leaf roll. Mild mosaic does not appear to be a problem with this variety. It is susceptible to scab, verticillium wilt and to virus leaf roll. The tubers are often rough and oversize and subject to growth cracks. They set fairly close to the surface of the ground and "sun green" unless care is taken to hill them. It is necessary to determine the

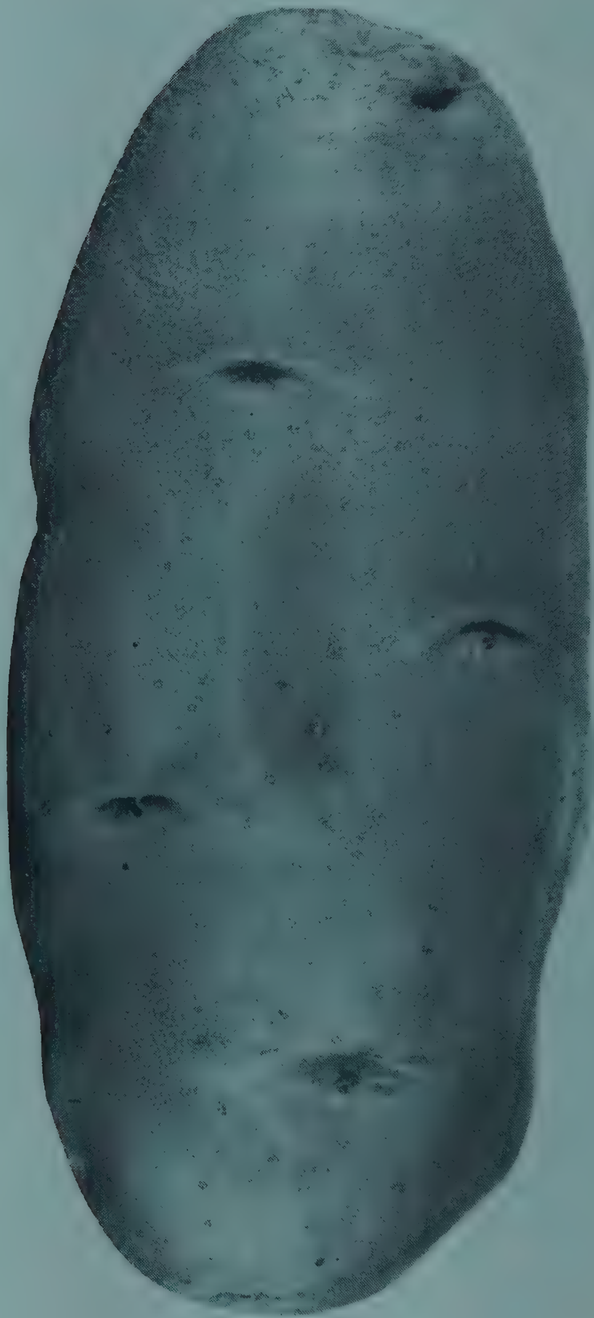

FIG. 14. WHITE ROSE

correct spacing for fertility and moisture conditions to produce a uniform crop of tubers. Cooking quality is rated good to excellent because of the high specific gravity of the tubers. It is popular for potato chip manufacture and makes excellent chips at harvest and after conditioning from storage. Market appeal of the tubers when properly handled is good. However, as it is becoming more widely disseminated, handling and

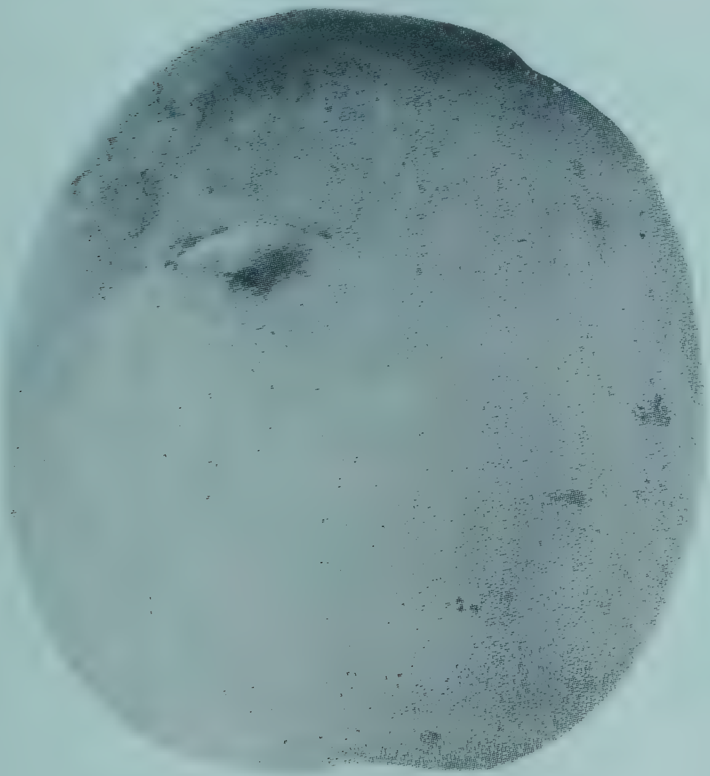

Fig. 15. Chippewa

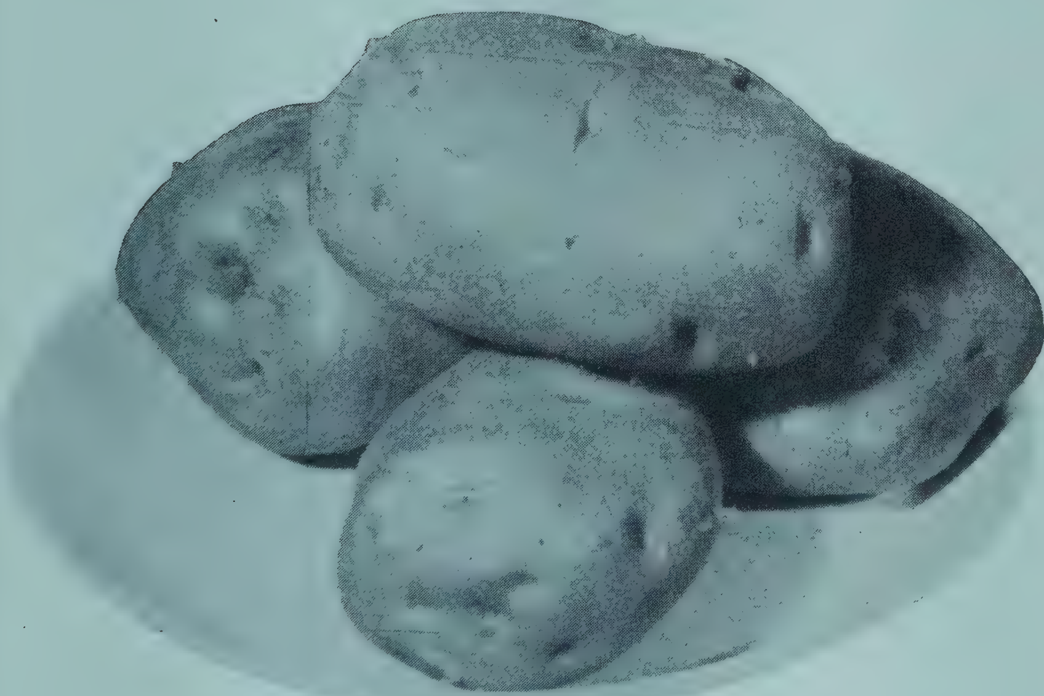

Fig. 16. Red LaSoda

transit problems are becoming evident. The tubers skin and bruise easily, especially if not fully mature. This provides easy access to rot organisms which cause tuber breakdown. This variety is in demand for the manufacture of potato chips and is extensively grown under contract to potato chip processors.

White Rose

Maturity late; tubers large, long elliptical, flattened, usually irregular; skin smooth, white; eyes numerous, medium in depth; flesh white.

White Rose is one of the very old potato varieties that is still grown commercially. It is particularly adapted to the irrigated sections of the west coast. When uniform moisture can be maintained it produces high yields of marketable tubers. Under adverse conditions it is quite subject to second growth, the tubers are shorter and the eyes are deeper. It is susceptible to most potato diseases. It is usually marketed at the time of year when the late northern crop is about gone and before the eastern crop is ready. Specific gravity is variable depending upon where it is grown and the time of year it is harvested. White Rose is utilized for potato chips in the early spring months when freshly harvested.

Chippewa

Maturity midseason; tubers large, elliptical to oblong, medium in thickness; skin smooth, dark creamy buff, eyes shallow, of the same color as the skin; flesh white.

The Chippewa variety was released in 1933 by the United States Department of Agriculture. It is widely distributed and very popular on peat or muck soils where it produces high yields of uniformly large tubers. It develops tubers of good shape early in the growth period and may be harvested as an early potato although the tubers are quite immature. The usual time to market this variety is just after the early crop and before the fall crop is ready. It is resistant to mild mosaic and net necrosis due to current season leaf roll infection. The potato is very susceptible to leaf roll, spindle tuber and scab. Were it not for susceptibility to scab, especially deep pitted scab, this variety would be outstanding on organic soils. The tubers have a thin, white skin which is subject to bruising when not carefully handled. Specific gravity of the tubers is relatively low, but is usually quite uniform in any one lot of potatoes. Cooking quality is fair and the cooked potato resists after cooking darkening. It remains intact after boiling. It is uncommon for the outer portions of the Chippewa tuber to slough off when boiled. It makes a light colored potato chip but because of low specific gravity and high fat absorption it has not found favor for potato chip processing.

Red LaSoda

Maturity early to medium early; tubers semi-round to slightly oblong, medium in thickness, skin smooth, dark red; eyes medium in depth; flesh white.

Red LaSoda is a deep red mutant of the LaSoda variety released in 1954. It is susceptible to most common potato diseases. The tubers are large and have a tendency to be somewhat rough. Specific gravity is usually low and this variety has doubtful use for processing. It has gained popularity because of its high yield, early maturity and deep red skin color.

Cherokee

Maturity medium early; tubers medium in size, roundish with blunt ends; skin smooth, creamy white; eyes medium in depth; flesh white.

Cherokee was released in 1951 for the muck soils of Iowa. It is now widely grown especially in the northeast and central states. It is a vigorous growing potato resistant to the common strains of late blight fungus, common scab and mild mosaic. It is susceptible to verticillium wilt. It produces a high yield of tubers with a very white smooth skin and an attractive appearance. The tubers are somewhat irregular in shape and become rough if allowed to grow too large. The cooking quality of the tubers is good. Specific gravity is high. Careful handling and good storage conditions are necessary to hold this variety. When bruised it is subject to wet storage rots. It is satisfactory for processing and makes good potato chips both at harvest and after conditioning.

This variety is popular because of the very white smooth skin, its scab resistance, yield potential and medium to early maturity.

Sebago

Maturity is late; tubers large, elliptical to round elliptical, medium in thickness; skin smooth, ivory yellow; eyes shallow; flesh white.

Sebago is a high yielding variety released by the United States Department of Agriculture in 1938. It possesses resistance to mild mosaic and field resistance to late blight. The tubers have a slight resistance to common scab and are quite resistant to late blight, seldom rotting because of blighted foliage. Sebago sets few tubers per plant so seed must be spaced closely to prevent over-size tubers. This variety is particularly susceptible to blackleg which often reduces the stand. Better stands are obtained from planting whole "B" size seed. The tubers have a tendency to cling to the vines at harvest time. It is sometimes necessary to pay a premium to induce potato pickers to handle this variety. This potato resists after cooking darkening and the specific gravity is high if the potatoes are fully

FIG. 17. SEBAGO

matured. They are an attractive appearing potato on the table stock market. Sebago potatoes are excellent for the manufacture of potato chips in the fall and early winter months provided they have not been stored below 50°F. When reducing sugars accumulate, conditioning for chips is unsatisfactory. The tubers have a short dormancy period usually developing sprouts in December and early January. This characteristic, plus the field resistance to late blight, has made this variety popular for the southern winter crop. Early harvested seed from the northern states does not need artificial treatment before planting in the south. For long storage periods some means of sprout inhibition—cold temperature or chemical—is necessary. In preliminary trials Michigan grown Sebago made satisfactory dehydrated potato flakes.

NEW VARIETIES

Potato breeders, encouraged by the availability of potatoes with resistance to specific potato diseases and a broader knowledge of the diseases, have been able to combine disease resistance with other desirable characteristics. Several varieties of recent introduction possess resistance to more than one disease as well as a potential for high yields of excellent quality tubers. Some of these have not been in commercial production for sufficient time to determine their adaptability to various environments and methods of production.

From many preliminary reports it would appear that **Saco, Merrimack** and **Delus** tubers are high in specific gravity and make excellent potato chips at time of harvest as well as when conditioned after storage. The **Saco** variety combines high yields with immunity from viruses A and X and the common race of late blight. The tubers are somewhat irregular in shape but predominately short and round. In some trials they are classified as rough. Saco has excellent potential for processing. The tubers are high in specific gravity, accumulate reducing sugars slowly in storage at 40°F., and condition readily at higher temperatures to make

FIG. 18. DELUS

light colored potato chips. French-fried Saco potatoes are of good color, texture and flavor. The high yield possibility plus the multiple disease resistance should make this variety economical to produce. A tendency for immature potatoes to sprout in warm soil may limit production to areas of moderate temperatures during the growing season.

Merrimack, a late variety with resistance to late blight and ring rot, produces good yields of smooth tubers. Specific gravity is high and the tubers make excellent potato chips at harvest time and after storage require only a short conditioning period at higher temperatures. The good yield, the high specific gravity, the market quality and the ability to

condition quickly after storage make this variety appear to be a good general purpose potato. The resistance to late blight and ring rot will lessen production costs. It should be a good potato in areas where scab is not a problem.

Delus is a medium to late maturing variety immune to the common race of the late blight organism. It produces average yields of very attractive, smooth, high specific gravity potatoes. The cooking quality of this variety is good and it has good eye appeal for the table stock market. When carefully stored it conditions to make very acceptable potato chips. However, at temperatures below 40°F. it is reported to develop internal mahogany browning. This condition has not developed in Delus potatoes stored at 40°F. at Michigan State University. A weakness of the variety in Michigan trials has been a poor stand of plants. Seed piece decay has been quite common, especially when cut seed was planted. The use of whole "size B" tubers has consistently improved the stand of plants and resulted in better yields of potatoes. The resistance to late blight, the high specific gravity and the attractive appearance of the tubers make this variety acceptable for processing and for the table stock market.

A scab resistant potato variety, **Huron,** was released in 1956 by the Canadian National Potato Breeding Program. This late variety produces high yields of good shaped, smooth, white skinned high specific gravity tubers. It sets the tubers early and economical yields of potatoes may be harvested for the early markets. When the tubers are mature they make good potato chips before storage and after conditioning.

Onaway and **Tawa** are two early scab resistant varieties released in 1956 by the Michigan Agricultural Experiment Station and the United States Department of Agriculture. The **Onaway** variety has a high yield potential and already has become popular in the early potato counties of Michigan. It requires close spacing in the row to avoid large rough tubers. Thorough spraying is necessary because of susceptibility of the tubers to rot caused by early blight. Specific gravity is not high and this variety has little value for processing. **Tawa** combines immunity from the common race of late blight and from virus X with scab resistance. It appears well adapted to organic soils where it produces a very uniform smooth round tuber. There is a tendency for the tubers to develop growth cracks under adverse conditions. It makes good potato chips and may be valuable where an early scab resistant variety is needed.

Of three recent releases from the Nebraska Agricultural Experiment Station, **Redbake** in 1956, **Excel** and **Haig** in 1957, **Redbake** is the only one reported to condition after storage for chip manufacture. It is one of the first red skinned potatoes with this characteristic. All three varieties have good cooking and market qualities.

Fig. 19. Tawa

Fig. 20. Onaway

Norgleam, Nordak and **Norland** are three early varieties with good tuber type released by the North Dakota Agricultural Experiment Station in 1957. **Norgleam** and **Nordak** are white skinned varieties with field resistance to virus Y. **Norland** is a moderately scab resistant red skinned variety.

CHOOSING A POTATO VARIETY

The varieties available to potato producers in the United States are increasing each year. The Certified Seed Potato Report of the United States Department of Agriculture for 1957 lists 56 varieties plus several not classified. Ten varieties represent 93 per cent of the 1957 production of certified seed potatoes.

The changing popularity of varieties may be seen in Table 7. Older varieties which were popular a decade ago are Irish Cobbler, Triumph, White Rose, Green Mountain, Russet Burbank and Russet Rural. Of these, only three remain in the top ten grown today. They are Russet Burbank, Irish Cobbler and White Rose. The Russet Burbank remains because of its particular adaptability to the irrigated sections of the Pacific Northwest and the market demand for this easily recognized variety. The Irish Cobbler is grown because of its early maturity and wide adaptability. The White Rose was the mainstay of the California potato industry and a market was built up for the "California Long White." The newer varieties, Red Pontiac, Kennebec, Red LaSoda and Cherokee are gradually gaining in popularity.

The problem of choosing a variety requires careful consideration. Growing conditions and production areas influence the performance of a variety. Stevenson *et al.* (1954) have shown there can be more difference between a variety grown under different conditions than between two good varieties grown under the same conditions. Older varieties have been tested in most areas and county agents or experiment station personnel will have knowledge of their performance. Information on newer varieties may not be as readily available.

New varieties are named because of differences in time of maturity, yield, appearance, resistance to disease, cooking and market qualifications and suitability for processing. The range of adaptability may be limited. Often varieties are released because of their value in a given location. Such a variety may be good in one area but of little value in another. Few varieties have the wide adaptation of the Katahdin and Irish Cobbler. This is evident in the over-state variety trials in Michigan where potatoes are grown from the Ohio border in the south to the shores of Lake Superior in the north (Table 8).

The transition from one variety to another is slow. Katahdin was re-

TABLE 7. RANKING OF THE IMPORTANT POTATO VARIETIES IN U. S. 1947 TO 1957 ARRANGED IN ORDER OF POPULARITY IN 195[illegible] [1]

	'47	'48	'49	'50	'51	'52	'53	'54	'55	'56	'57
Katahdin	1	1	1	1	1	1	1	1	1	1	1
Russet Burbank	7	5	6	3	4	2	3	3	2	2	2
Red Pontiac	..	9	9	8	8	4	4	4	3	3	3
Irish Cobbler	2	2	3	2	2	3	2	2	4	4	4
Kennebec	..	..	26	12	6	7	7	7	6	6	5
White Rose	4	4	5	5	5	6	5	5	5	5	6
Chippewa	6	5	4	6	9	10	8	8	7	7	7
Red LaSoda	..	..	..	..	..	..	42	44	21	15	8
Cherokee	..	..	..	..	..	15	15	9	8	8	9
Sebago	8	10	11	10	12	11	10	10	10	9	10
Red McClure	9	7	10	11	10	17	17	18	11	11	11
Triumph	3	3	2	4	3	5	6	6	9	10	12
Green Mountain	5	6	7	7	7	8	9	13	12	14	13
Russet Rural	10	11	12	13	13	13	13	12	14	12	14
Ontario	15	16	15	14	14	9	11	17	17	19	15

[1] From Certified Seed Potato Reports U. S. Dept. Agr. Agr. Mkt. Service Crop Reporting Board.

TABLE 8

YIELD IN HUNDRED WEIGHTS PER ACRE AND SPECIFIC GRAVITY OF POTATOES GROWN IN OVER-STATE VARIETY TRIALS IN MICHIGAN IN 1956[1]

Variety	Ingham Co.		Missaukee Co.		Presque Isle Co.		Bay Co.		Montcalm Co.		Delta Co.	
	Yield	Sp. Gr.	Yield	Sp. Gr.	Yield	Sp. Gr.	Yield	Sp. Gr.	Yield	Sp. Gr.	Yield	Sp. Gr.
Merrimack	347	1.083	234	1.082	212	1.086	131	1.077	254	1.090	373	1.082
Delus	365	1.084	273	1.081	221	1.082	195	1.080	315	1.078	405	1.075
Saco	495	1.082	348	1.082	303	1.084	237	1.067	394	1.084	505	1.076
Cherokee	294	1.075	279	1.077	200	1.075	83	1.067	245	1.075	301	1.076
Kennebec	413	1.072	252	1.073	201	1.073	173	1.066	287	1.073	374	1.074
Katahdin	382	1.074	245	1.073	226	1.075	146	1.063	319	1.075	328	1.072
Irish Cobbler	348	1.072	257	1.074	174	1.072	126	1.064	294	1.075	317	1.072
Tawa	265	1.068	218	1.072	176	1.071	111	1.065	251	1.074	297	1.073
Sebago	257	1.070	191	1.071	176	1.072	135	1.065	187	1.075	306	1.070
Boone	277	1.072	223	1.073	196	1.071	60	1.063	180	1.068	308	1.067
Red Beauty	258	1.068	190	1.065	139	1.065	139	1.062	246	1.081	321	1.075
Antigo	368	1.070	212	1.069	142	1.066	157	1.060	296	1.072	296	1.073
Red LaSoda	508	1.068	299	1.068	268	1.068	219	1.059	334	1.069	503	1.071
Onaway	369	1.067	270	1.068	199	1.065	150	1.064	312	1.068	350	1.070

[1] Courtesy of D. R. Isleib.

leased in 1932. It was 15 years before it ascended to the number one position in the nation. Table 7 shows the gradual increase or decline of varieties in a ten-year period.

One of the main reasons for the loss of favor of varieties has been the lack of disease resistance and the failure to meet the requirements of changing market conditions. The first rough, deep-eyed, variable-colored varieties would have little appeal in a supermarket today. All other characteristics being equal, resistance to one disease or insect makes a variety better than a susceptible one. New varieties are screened for disease resistance before they are named. However, pathogens are frequently complex. A variety may have resistance to a specific disease but after a few years in production pathogens with the ability to destroy the plant may build up.

When a variety is released, it is not advisable to buy large quantities of high-priced seed because of reported superiority in another locality. It is necessary to determine how the variety reacts to local environmental conditions. One should test the variety first on a small scale. Growers have learned to produce the maximum from the varieties they have been growing. A new variety may not attain its maximum yield of high quality tubers with the old techniques. Changes may be required in spacing within the row, in the amount of fertilizer and irrigation water applied, in the spray program and other cultural practices.

No variety has yet been released that will meet the needs of all potato growers. It is doubtful if such an ideal variety will be developed. However, there is a demand for each new variety. The best of these increase against the competition of established varieties because of special characteristics they possess.

To be popular a variety must yield well. Yield is the total effect of inherent potential, adaptation to environment and disease resistance. High yield is not the only reason for popularity. Eye appeal or attractiveness, marketability, reliability, cooking and processing quality are of prime importance. A variety must be high in total solids. The modern emphasis on processing requires a high dry matter content plus all the other characteristics which make a potato valuable for processing.

Certain new varieties such as Kennebec and perhaps Saco, because of yield, specific gravity and disease resistance, have great promise for processing. However, they may have to be grown under contract to a processor because of characteristics unfavorable to the table stock market. A good variety should fulfill the requirements of both the processor and the table stock market. Such a variety will provide a broader market for the grower and assure readily available supplies to the processor.

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Ora Smith

Effect of Cultural and Environmental Conditions on Potatoes for Processing

The quality of potatoes for processing is affected tremendously by cultural and environmental conditions during the growing season. There are many factors which contribute to high quality potatoes for processing such as high specific gravity or dry matter content (except for potatoes to be canned), low sugar content, especially reducing sugars, high degree of maturity, low peeling loss and relative freedom from disease. It is necessary or desirable for the processed product to have an attractive color and a good flavor.

Cultural and environmental conditions which influence potato processing quality are (1) date of planting, (2) soil type, (3) soil reaction, (4) soil moisture, (5) season, (6) location, (7) mineral nutrition of the plants, (8) cultivation and weed control, (9) spray program for control of insects and diseases, (10) temperature during the growing season, (11) time and method of killing vines and (12) time of harvest. In addition to the cultural and environmental factors the choice of variety for processing is of great importance.

FACTORS AFFECTING SPECIFIC GRAVITY OR DRY MATTER OF POTATOES

Variety

Selection of raw material on the basis of dry matter content is very important to most processors. Yields of potato chips and French fries and texture of French fries, canned and reconstituted dehydrated potatoes are dependent upon and directly related to the dry matter content of the raw stock. For every increase of one per cent in dry matter of raw stock the potato dehydrator and chip processor may obtain an increase of approximately one pound or more of finished product from each 100 lbs. of peeled raw potatoes. The dry matter content of potatoes varies between varieties. Some varieties are inherently of higher dry matter content than others although dry matter of all varieties is influenced greatly by environmental conditions. Irrespective of fertilizer application, cultural conditions and of other growth factors, certain varieties are consistently high in total solids and others are usually low in solids if growing conditions are the same for all. Green Mountain variety is one that usually is high and Pontiac, Ontario and Chippewa rather consist-

ently are low in dry matter. Green Mountain, however, is not of high quality for processing for other reasons which will be discussed later in this chapter. Yields of processed potatoes would be appreciably higher from some varieties than from others, amounting to as much as 33 per cent increase in yield of dehydrated product by proper choice of varieties of high dry matter.

The specific gravity method enables the processor to find and select tubers for high solids content with minimum effort and time. This is highly desirable for potatoes to be dehydrated, chipped, French fried or converted to starch or alcohol.

In dehydration tests in California with western grown potatoes (Cruess and McKinney 1943), the dried product of Russet Burbank was rated highest in quality of seven varieties. White Rose was placed second. Both gave dried products of light color and good cooking quality. Considerably less desirable in color and flavor were Houma, Sebago, Chippewa, Sequoia and Bliss Triumph. Although the White Rose variety comprised about 80 per cent of the potato acreage in California during World War II, dehydrators in that state preferred Russet Burbank even though it necessitated longer shipment of the raw stock. It is higher in total solids than White Rose tubers, gives a lower drying ratio and a greater yield of dry product (about 4.5 to 1 compared with about 5.2 to 1). The higher total solids of Russet Burbank was due partly to varietal differences and partly to differences in growing conditions in the two areas.

High specific gravity in a lot of potatoes does not make absolutely certain that the dehydrated product will have a highly desirable texture, but it is quite certain that raw stock with low specific gravity will not make a product of superior consistency or texture (Caldwell *et al.* 1943). No one variety grown in all places is consistently superior in texture. Very good to excellent texture is correlated with moderately high to high specific gravity without relation to variety or place where grown.

Yield of dry product calculated on the fresh weight basis varies widely partly due to varietal difference. Yields from 10.9 to 27.69 per cent have been reported. Variation in dry yield is due largely to differences in specific gravity of fresh material and there is high correlation between specific gravity and yield of dry product.

Varieties which were used principally in the Eastern United States for dehydration during World War II were the Katahdin, Chippewa, and Sebago. Here again, these varieties are not of highest specific gravity but they are relatively low in reducing sugars, when well matured, and therefore are a lesser problem to dehydrate than a variety such as Green Mountain. The Green Mountain was grown extensively in the North-

east but because of its high reducing sugar content and its tendency to discolor, it was used only to a small extent. For similar reasons it is never used for chips because of its tendency to become too dark. Smooth Rural and Russet Rural were used in a limited amount for dehydration. They are of low reducing sugar content and result in a desirably colored processed product. They also are rather high in specific gravity and yields of processed products are satisfactory.

During the peak of the dehydration period in World War II thousands of bushels of potatoes were purchased for dehydration primarily because of their attractive outward appearance. It was several years before other factors were known to be important. Large quantities of muck grown potatoes were dehydrated in the Eastern United States. These potatoes usually are of low specific gravity and result in low yields of dehydrated product. However, most of them were of good exterior appearance and also were likely to produce a dehydrated product of good color.

All other things being equal, high specific gravity is more to be relied upon in purchasing tubers for dehydration than the variety or the place of production (Caldwell *et al.* 1944A). The same variety grown in two areas may have different drying characteristics, particularly their drying ratios (Wiegand *et al.* 1946).

Freshly dug Idaho grown potatoes varied in solids content from 18 to 30 per cent with the majority of the samples in the range of 19 to 23 per cent (Stamberg 1945). Individual potatoes from the same hill or plant vary in total solids. Total solids has no relation to tuber size. Total solids of Netted Gem potatoes grown in Washington varied from 20.3 to 24.5 per cent (Bedford 1945). Johnson and Boyle (1919) found that the dry matter content of tubers of the same variety grown under similar conditions varied from 21.07 to 27.18 per cent. Tubers of the same variety grown under different conditions had a range of dry matter from 17.0 to 26.6 per cent. Thirty-nine varieties grown under similar conditions varied in dry matter from 17.4 to 27.5 per cent. In England the spread in dry matter per cent between seven varieties in any one year was 20.1 for Arran Banner to 25.8 for Golden Wonder (Wager 1946). Ten varieties grown under the same conditions in Western New York varied in per cent dry weight from 19.01 in Chippewa to 25.80 in Green Mountain. In three other areas in the state in the same year the extremes were Chippewa 20.44, 17.63 and 16.28 per cent and Green Mountain 25.22, 22.53 and 21.44 per cent respectively (Nash 1941).

There is no dry matter value characteristic of a variety, however, since there is variation from year to year and between areas, soil types, soil moisture and other growing conditions.

Date of Planting

This factor is very important in determining dry matter content and maturity of potatoes. Early planting lengthens the season of growth and results in greater maturity and usually in higher dry matter content at harvest than from later plantings. The earlier that plants appear above ground the sooner they will begin manufacture of food by photosynthesis and therefore, the more mature they will be at any subsequent date of harvest. If the soil is dry or cold after planting, the time of comeup will be delayed and the growing season, therefore, shortened. Hence, date of plant emergence actually is more important than date of planting for determining maturity and dry matter content of potatoes.

Date of planting is determined largely by the prevailing temperatures in any certain area and by the moisture content and other characteristics of the soil. Some growers plant those fields first with potatoes which they intend to grow and market for processing. They often choose those fields which dry out earliest and can be prepared first for planting. This type of soil is likely to enable plants to grow rapidly during the season and to attain a greater degree of maturity before harvest. Metzger (1937A) planted Russet Burbank potatoes at weekly intervals in Colorado from May 4 to June 15. At harvest time, October 10, it was found that the dry matter content decreased from 25.34 per cent from the first planting to 23.51 per cent from the last planting (see Table 9).

TABLE 9

INFLUENCE OF PLANTING DATE ON DRY MATTER CONTENT OF POTATOES[1]

	Dry Matter
Planting Date	Per cent
May 4	25.34
May 11	24.88
May 18	24.88
May 25	24.33
June 1	23.71
June 8	23.59
June 15	23.51

[1] From Metzger (1937A).

Smith and Nash (1942) found similar results in New York with the Smooth Rural variety. Employing ten fertilizer combinations with several dates of planting it was found that highest specific gravity tubers resulted from the first planting and lowest from the latest planting.

Soil Type

Type of soil in which potatoes are grown may affect dry matter content of tubers because of the water holding capacity, drainage, aeration,

structure, temperature or fertility. Any of these factors could cause differences in dry weight of potatoes grown in these soils but they may also balance each other in effects on dry weight, resulting in no change. For instance, a sandy soil would likely be of lower moisture content than a loam or clay loam soil. In a wet season this could be an advantage and result in potatoes of higher dry matter. In a dry season, however, it may result in lower yields but the potatoes may still be high in dry matter unless soil and air temperatures are quite high. A soil high in moisture content usually will be several degrees cooler than a similar soil of low moisture content. This cooler soil may result in higher specific gravity tubers because less starch and sugars are lost from the potatoes by respiration.

Numerous comparisons in areas of many parts of the world, through a period of years, show that higher dry matter potatoes usually are grown on mineral or upland soils than on muck, peat or fen soils in the same area. In England, Wager (1946) found greatest differences between potatoes grown on fen, blackland and peat soils compared with those on sands, gravels and light loam soils; potatoes from the latter soils had the highest dry matter content. Wager concludes that the factor responsible for the variation in content of dry matter of the potatoes is the available water content of the soils; the soils lowest in available moisture produce the highest dry matter potatoes. In Estonia, Aamisepp (1936) showed that for a twelve-year period and for six varieties, potatoes grown in muck soil averaged 14.38 per cent starch, those in loam soil averaged 16.32 per cent while those in sandy soil averaged 18.52 per cent. In Western New York the average dry matter content of ten varieties of potatoes grown in gravelly silt loam soil was 22.31 per cent and of those grown in muck or peat soil it was 18.72 per cent (Nash 1941). When soils from these two areas were transported to a third location and potatoes grown in them, no differences in dry matter content were obtained. This indicates that soil type, *per se*, has little or no influence on dry matter content of potatoes.

Soil Reaction

Soil reaction apparently has a minor effect on dry matter content of potatoes. Very few studies are reported on the relation of these two factors. Klapp *et al.* (1936) reported that in Germany highest yields of starch were obtained in neutral or weakly alkaline soils. Part of this increase in yield of starch per acre, however, was a result of increased yields of potatoes in the neutral or weakly alkaline soils. Smith (1938) found that the starch percentage of potatoes grown in soils ranging in pH from 5.4 to 6.05 was higher than that in tubers grown in soils at either higher

or lower pH values. In soils lower than pH 5.0, potatoes matured earlier, at relatively high temperatures, than in soils of a less acid nature. This probably was the cause of lower dry matter content in those potatoes growing in highly acid soils. It was also found (Smith 1937) that potatoes grown in soil of low pH retain their shape better and slough and break up to a lesser extent when boiled than tubers which had been grown in less acid or alkaline soils. In experiments on permanent soil reaction plots Smith and Nash (1941) detected that the average specific gravity of potatoes increases in soils of pH 4.88–5.3 to that of pH 6.73–7.19. A slight decrease in gravity occurred in potatoes grown in soils more alkaline than pH 7.19. Soil tests showed that those soils of high pH contained the largest amounts of soluble calcium, phosphorus and magnesium. These are important ions in increasing dry matter content of potatoes as shown in a following section.

Soil Moisture

Differences in soil moisture as a result of rainfall, irrigation, type of soil, run-off, evaporation, shading and other factors have an effect on dry matter content of potatoes and their quality for processing. In arid and semiarid areas it is necessary that potatoes receive irrigation in addition to normal rainfall. In more humid areas the potato grower has the choice of utilizing rainfall only or of supplementing it with irrigation. Potatoes respond well to an ample soil moisture supply by an increase in yield. This additional soil moisture may, however, produce potatoes of lower dry matter content. Overhead application of 4.52 inches of irrigation water in July, August and September to supplement rainfall resulted in decreases in dry matter content of potatoes from 23.28 per cent for unirrigated to 22.46 for irrigated potatoes (Smith and Nash 1941).

It is highly desirable to have a uniform moisture supply in the soil at all times during the growing season. Applying an overabundance of water and then waiting too long for the next application may result in misshapen, second growth and growth cracked potatoes of relatively low yields. For high dry matter potatoes it is well to withhold irrigation late in the season so that the potatoes will become more nearly mature at harvest. Application of water often results in decreased dry matter in potatoes as mentioned earlier. However, it also has been found that irrigation may have no effect on dry matter and in some instances has increased it.

Pratt *et al.* (1952) found that in 1949 irrigated potatoes had a specific gravity of 1.070 and unirrigated 1.068. In 1950 irrigated and unirrigated potatoes had the same specific gravity, 1.067, whereas in 1951 irrigated potatoes were 1.078 and unirrigated potatoes averaged 1.081. This indi-

cates that there are at least two sets of factors involved in dry matter production relative to soil moisture. A high available moisture supply in itself will tend to lower dry matter content of tubers. At the same time, however, this moisture tends to keep the soil cool and at a more even day and night temperature than a soil lower in moisture (Smith 1956 and 1958B). If the growing season is one of high temperatures, the addition of water lowers the soil temperature and at this lower temperature less solid matter in the potato is lost by respiration. Therefore, more photosynthate remains in the tuber resulting in higher dry matter in the irrigated potatoes. At a lower temperature growing season, more nearly optimum for potato growth, the addition of water may result in lower dry matter content of potatoes. Water makes nitrates more available to the plants, this prolongs the growing season and delays the storage of solids in the tuber. Consequently, at time of harvest, dry matter may be lower than where no water was applied. The weather data of Pratt *et al.* (1952) show that in 1949, when irrigation increased dry matter of potatoes, the August temperatures were the highest of the three years. Apparently the soil cooling effect of the added water in 1949 resulted in a higher per cent of the photosynthate being stored and retained in the tubers. Gauman and Hafliger (1949) showed that glucose and starch contents of potatoes were optimum at a soil temperature of 68° to 72°F. and decreased rapidly at higher temperatures.

Effect of Season

The dry matter content of the same varieties may vary considerably from season to season in the same locality. These variations may be the result of differences in date of planting and harvesting, soil moisture, temperature, fertilization program, application of insecticides and fungicides, vine killing and other cultural and environmental factors. The effects of these factors on dry matter of potatoes will be discussed separately.

Determination of specific gravity of thousands of samples of potatoes in New York State for a 19-year period indicates considerable variation in specific gravity or dry matter content of the same variety between seasons. Table 10 shows a typical example.

TABLE 10

VARIATION IN SPECIFIC GRAVITY OF POTATOES OF THE SAME VARIETIES BETWEEN SEASONS[1]

Variety	1940	1950
Sebago	1.098	1.082
Katahdin	1.092	1.083
Irish Cobbler	1.085	1.082
Pontiac	1.081	1.071

[1] From Smith (1951B).

Effect of Location

Striking differences occur in specific gravity or dry matter content of the same varieties of potatoes when they are grown in various localities. These variations occur as a result of differences in environmental conditions which have been mentioned. Many examples are available which show remarkable differences in specific gravity or dry matter of potatoes grown in different areas during the same season. The data of Table 11 show the variations occurring within the same state.

TABLE 11

EFFECT OF LOCALITY ON PER CENT DRY WEIGHT OF SEVERAL VARIETIES OF POTATOES[1]

Variety	County in New York			
	Tompkins	Steuben	Suffolk	Wayne
Green Mountain	25.80	25.22	22.53	21.44
Smooth Rural	23.33	24.04	...	20.72
Houma	22.48	23.67	21.78	19.69
Sebago	25.47	21.38	20.42	18.21
Katahdin	24.12	23.57	20.40	17.81
Warba	22.99	21.01	20.15	18.53
Irish Cobbler	22.00	21.07	20.60	20.52
Pontiac	21.53	21.83	...	17.07
Chippewa	19.01	20.44	17.63	16.28
Earlaine	21.27	20.88	17.78	16.98
Average	22.80	22.31	20.10	18.72

[1] From Nash (1941).

These differences in dry matter between locations are due primarily to soil moisture and temperatures prevailing during the growing season.

Mineral Nutrition

As the general level of fertility of the soil is increased, the specific gravity and dry matter of tubers grown in these soils decrease (Smith and Nash 1938, 1939, 1940, 1941 and 1942; Blood and Haddock 1939; Prince *et al.* 1940; Nash and Smith 1940; Drew and Deasy 1942; Cowie 1943; Caldwell *et al.* 1943; Smith and Kelly 1946).

There was a progressive decrease in specific gravity of Smooth Rural potatoes from 1.097 with 1,000 lbs. 4-8-8 fertilizer per acre to 1.084 with 3,000-lb. applications (Smith and Nash 1941). A consistent decrease in specific gravity of Sequoia and Green Mountain potatoes resulted from 500 to 1500 lbs. per acre applications of 8-16-14 fertilizer. Sequoia decreased from 1.098 with 500 lbs. of fertilizer to 1.081 with 1500 lbs.; Green Mountain was reduced from 1.097 to 1.087. Yield of dehydrated product in Sequoia decreased from 27.69 per cent with the low rate of application to 23.54 per cent with the higher rate. With the Green Mountain variety yields of dehydrated product were decreased from 26.82 per cent to 25.29

per cent (Caldwell *et al.* 1943). Yungen *et al.* (1958) found in Eastern Oregon that increased rates of nitrogen fertilizer from 0 to 200 lbs. nitrogen per acre resulted in decreased specific gravity of potatoes sampled at six times from early tuber set to near maturity (see also p. 97).

Nitrogen

Greatest yield response in potatoes in most potato growing areas results from application of nitrogen, either in a complete fertilizer or as a side dressing or application in irrigation water. Nitrogen promotes extensive vine growth and tends to prolong the season of growth. As a result, potatoes do not become mature at harvest and, therefore, chemically are not likely to be high quality processing potatoes after several months storage at 40°F. Immature potatoes are more difficult to store and lose more weight in storage than mature ones. They also are much more difficult to recondition after storage in order to be assured of potatoes of low reducing sugar content. In New York, Smith and Nash (1940) found that applications of 60 lbs. of nitrogen per acre in complete fertilizers consistently produced potatoes of higher dry matter than those fertilized with 120 lbs. nitrogen. Metzger (1937B) states that in Colorado potatoes fertilized with ammonium sulfate were consistently low in starch and dry matter.

In Kern County, California nitrogen is the predominating fertilizer element affecting yield of White Rose potatoes. Lorenz (1944) found that in this area the starch content of potatoes decreased from 17.0 per cent in tubers produced without nitrogen to less than 13 per cent in tubers grown on plots receiving 210 lbs. of nitrogen per acre. Omission of nitrogen from the fertilizer greatly reduced the absorption of phosphorus. Calcium was highest in plants grown without nitrogen and lowest in plants grown without phosphorus. Low phosphorus and low calcium in potatoes as a result of high nitrogen applications tend further to reduce the dry matter of potatoes. Smith and Nash (1940) showed the importance of the calcium ion relative to dry matter in potatoes. Calcium chloride applications to the soil produced tubers of higher specific gravity than equal applications of potassium chloride.

Dunn and Nyland (1945), however, found that nitrogen fertilizers had no apparent influence on the specific gravity of Minnesota grown potatoes. Michael (1943) states that starch and dry matter had a slight but uniform tendency to be higher in tubers when nitrogen was added at two stages of growth than when all nitrogen was added at the start. Shestakov and Pleshkov (1954), however, found that preplanting fertilization resulted in tubers higher in starch than from later fertilizer reinforcement.

Phosphorus

This element when applied to the soil rarely has a depressing effect on dry matter of potatoes. Little or no increase in specific gravity or dry matter has been found by Blood and Haddock (1939); Smith and Nash (1940) and Lorenz (1944). Appreciable increases in per cent of starch or dry matter by application of various levels of phosphorus were obtained by Metzger (1938), Prince *et al.* (1940), Gericke (1940), Dunn and Rost (1945), Dunn and Nyland (1945), and Fineman (1947).

Potassium

Potash fertilizers also affect the dry matter content of potatoes. The most widely used form of potash in fertilizers is muriate of potash (KCl). When heavy applications are made, either alone or in a complete fertilizer, dry matter content of potatoes is decreased. This has been shown by Houghland and Schricker (1933), Smith and Nash, 1940, 1941, 1942, Dunn and Rost (1945), Pollard *et al.* (1946), Terman *et al.* (1949), Baker *et al.* (1950), Hill (1953) and others.

This decrease in dry matter content of potatoes is due largely to the chloride ion in the muriate of potash rather than to the potassium ion. Therefore, the use of some other form of potash should increase the dry matter content of potatoes. The sulfate form of potash usually results in higher dry matter or starch content of potatoes than equivalent quantities of potash in the chloride form (Kuhnke 1935; Asdonk and Jacob 1940; Nemec 1940; Smith and Nash 1941; Drew and Deasy 1942; Cowie 1943; Smith and Kelly 1944B and 1946; Dunn and Nylund 1945; Terman 1949; Lucas *et al.* 1954, and Latzko 1955).

The effects of the various sources of potash on starch and dry matter of potatoes also may be influenced by the pH or reaction of the soil. Thun (1943), for instance, found that the starch content of potatoes was increased by addition of sulfate of potash to neutral soils and by application of potash-magnesia to acid soils. The effect of potash-magnesia, however, was probably due to the presence of magnesium since this element often is at a low level in acid soils. Nemec (1940) also found that starch content of potatoes is decreased with kainite and 40 per cent potash fertilizers to a greater extent in strongly acid soils than in those of higher pH. In soils below pH 5.5 applications of potash salts depressed the starch content of potatoes especially with kainite. On slightly acid to alkaline soils applications of potash in chloride form caused only a slight reduction in starch content of tubers and applications of sulfate of potash increased the starch content (Nemec 1937).

There also is a relationship between the exchangeable potassium in the soil, the potash applied in the fertilizer and the dry matter content of

potatoes. Terman *et al.* (1953) found that dry matter content of tubers decreased as potash applications increased except when grown on soils very low in exchangeable potassium. The dry matter content of tubers increased to exchangeable soil potash levels of 200 to 350 lbs. and decreased at higher levels. When 180 lbs. per acre of K_2O as KCl was added in the fertilizer, the dry matter content of tubers decreased as the exchangeable soil potash increased. It is postulated that the higher dry matter content of potatoes fertilized with sulfate of potash may be a result of the relative uptake of potassium rather than the nature of the anion absorbed.

There is some evidence that the various forms of potash influence the enzyme content or the functions of enzymes in potatoes which may indirectly affect the starch and dry matter content of potatoes. James (1930) states that application of potassium increases catalytic activity and, therefore, may increase efficiency in starch formation. Latzko (1952, 1954 and 1955) in a series of studies in Germany has found that the hydrolytic activity of carbohydrases, such as invertase, amylase and B glucosidase, is inhibited by the chlorine ion and increased with sulfate ions. There was increased activity of carbohydrate decomposing enzymes when the plants were fertilized with sulfates and a decrease in activity resulted from chloride nutrition of the plants. Sulfate nutrition resulted in better transformation conditions of carbohydrates formed in the leaves.

Magnesium

In many areas this element is not available in soils in sufficient concentration to result in high yields. Magnesium may be applied in the form of sulfate of potash-magnesia, Epsom salts, calcined kieserite, dolomitic limestone or other forms. It is very likely to be deficient in acid soils. A high level of potash fertilization induced severe magnesium deficiency in Ireland (Walsh and O'Donohoe 1945). Magnesium deficiency caused a considerable decrease in yield but had no effect on the starch content of tubers. Chucka and Brown (1938) found that magnesium as $MgSO_4$ applied as a spray was absorbed by the foliage and resulted in significant increases in yields. In Germany, Marholdt (1922) found that $MgCl_2$ resulted in lowering the starch content of potatoes. The starch content was increased only when magnesium was applied as sulfate of potash-magnesia. Smith and Kelly (1946) obtained potatoes with higher specific gravity from sulfate of potash-magnesia than from muriate of potash but somewhat lower than when sulfate of potash was the source of potassium.

Minor Elements

In a few potato growing areas it has been shown that certain minor elements are in deficient quantities for maximum yields and for best

quality. Smith and Nash (1938) found that potatoes grown in sand cultures deficient in copper, manganese, boron and iron contained higher percentages of sucrose than those grown in complete nutrient solution.

Green Manures and Rotations

Results of several experiments indicate that organic matter incorporated in the soil in the rotation with potatoes may have some effect on the dry matter content of the tubers. Smith and Nash (1940) in a study of ten rotations found that the highest specific gravity tubers were produced where potatoes were grown every year on the same soil and received no fertilizer or cover crop. Lowest specific gravity tubers were grown following a crop of soybeans for hay. On the other hand Turlapova (1939A and 1939B), working in Russia, found that lupines plowed down create conditions favorable for the accumulation of starch in potatoes.

Cultivation and Chemical Weed Control

These have relatively minor effects on dry matter content of potatoes. Cultivation by a number of conventional methods and implements may affect the moisture content of soil and in this way influence dry matter content of tubers. Cultivation which results in moisture conservation may produce growth similar to that received from irrigation; if moisture content is high it may result in decreased dry matter content of tubers. On the other hand, if this conserved moisture tends to maintain a lower soil temperature during hot, dry periods it would likely result in no change or an increase in dry matter. Any methods of cultivation which hasten moisture loss by excessive or deep stirring of the soil would likely have the opposite effect.

Soil moisture may be reduced rapidly by transpiration of water from leaf surfaces of weeds if they are not destroyed when small. Obviously this could affect soil moisture and, hence, dry matter content of potatoes.

In many areas weeds may be controlled adequately with pre-emergence applications of such chemicals as dinitro ortho secondary butyl or amyl phenols or one of a number of the dinitro group. This may result in an alteration of the soil moisture content and, therefore, have an affect on dry matter content of tubers.

Spray Program for Control of Insects and Diseases

Spraying or dusting for the control of insects and diseases, either by plane or ground equipment, is necessary in practically all potato growing areas. Control of insects and diseases has an effect on potato processing quality. Without good control, early death of plants occurs, yields are reduced and processing quality of the tubers is impaired. With the proper application of insecticides and fungicides the potatoes continue to grow,

remain green and do not die or mature naturally but must be killed by frost, chemical or mechanical means. As a consequence, the chemical composition of these immature tubers often is such that they are poor risks for processing.

DDT probably is the most widely used insecticide on potatoes in this country. Due to its excellent control of insects the plants continue to remain active photosynthetically and growth is terminated suddenly by frost or the application of vine killers while the plants are still immature. This often results in lower dry matter tubers and lower yields of chips (Smith 1950). DDT sprayed on the vines lowered the specific gravity of the tubers and the yield of chips. It also resulted in a darker chip because of the higher reducing sugar content of the immature tubers. Heavy applications of DDT added to the soil the previous fall had no effect on color of chips. Stevenson *et al.* (1955) found that the average per cent solids of six potato varieties in 1953 which had been sprayed with water only was 20.5; those sprayed with basic copper only, was 20.5; those sprayed with basic copper plus DDT plus parathion was 20.2 and those sprayed with DDT plus parathion was 19.8 per cent. In a severe late blight year total solids averaged 18.4 per cent with DDT spray, 20.3 per cent with basic copper spray and 20.7 per cent with DDT plus basic copper. Smith (1951A) found that unsprayed plants grown on Long Island in a severe late blight season were killed early resulting in low specific gravity and low yield of chips. Yield from plants sprayed with Bordeaux mixture either all season or alternated with Dithane D 14 resulted in high yields of chips. Further work, Smith (1956 and 1957A), has shown that yields of potatoes are not decreased but that the specific gravity of potatoes is increased by omitting DDT from the last two or three fungicide sprays in late summer or early fall.

Table 12

EFFECT OF DDT APPLICATIONS TO POTATOES ON YIELD AND COLOR OF CHIPS. KATAHDIN GROWN IN 1949[1]

Spray Treatment	Yield of Chips[2]	Color[3]
	Per cent	
No DDT	32.80	90
DDT spray, 10 times	28.41	80
No DDT spray, but 100 lbs. DDT added to soil in fall of 1948	32.89	90

[1] Smith (1950).
[2] Per cent of weight of peeled potatoes.
[3] 80 = commercially acceptable color; 90 = very light color.

Temperature During the Growing Season

Late in the growing season temperatures ranging from 60° to 75°F. result in potatoes of higher dry matter content than those produced at

higher temperatures. This is a result of the greater loss of carbohydrates by respiration at the high temperatures.

Time and Method of Killing Vines

As a result of the use of more efficient insecticides and fungicides in recent years and with other production methods which prolong the growth of potatoes in the field it is now necessary in many cases that the potato vines be killed by mechanical or chemical means before harvesting. Formerly the plants died rather early as a result of insect and disease damage. As the plants slowly matured there was translocation of food from the leaves and stems to the tubers. This food, usually in the form of sugars, was converted to starch in the tubers resulting in high dry matter or specific gravity. When modern rapid methods of vine killing are employed there is little or no opportunity for transfer of food from tops to the tubers. As a result the tubers are of lower dry matter and of different chemical composition, usually less starch and higher sugars. Similar to the increase in dry matter by delaying date of harvest is the dry matter increase obtained by delaying date of killing the vines. In some years, killing vines late results in rather large increases in dry matter of tubers as compared with early kill. In other seasons, due to the differences in growing conditions, particularly rainfall and temperature, the early killed plants may produce tubers as high in dry matter as those killed later. Akeley *et al.* (1955) found that in 2 of 3 years there was a significant loss in dry matter of potatoes resulting from early vine killing in Maine. Chips made from Sebago, Chippewa, Katahdin, Teton, Mohawk, Kennebec and Green Mountain, but not Irish Cobbler, improved in color as date of vine killing was delayed from August 15, through August 25, and September 4 to September 18, which was the last date of killing vines (see also p. 99).

The chemical composition of vine-killed potatoes is likely to be different from those which were not from killed vines. This may result in color differences of chips made from the two lots. In some instances the color of chips from vine-killed plants is lighter than those from plants not killed; in other situations it is the reverse. Evidently the environmental conditions such as temperature and soil moisture that prevail before and after the vines are killed, determine the chemical composition of the tubers and the resultant color of the chips and other processed products. It is best, therefore, to kill potato vines slowly if possible or to kill them as late as possible without subjecting the potatoes to temperatures under 40°F. Experiments show that specific gravity of tubers is higher from plants killed slowly, such as by chemical sprays, than by rotobeating, if both are done on the same day (McGoldrick and Smith 1948). Many

growers kill vines with a spray application of sodium arsenite or one of the dinitro compounds and then about a week later they rotobeat the remaining mostly dead vines for convenience in harvesting.

Time of Harvest

Mature potatoes as a rule are much more desirable for processing than those less mature. There is good correlation between maturity, specific gravity of the raw tubers and yield of processed product. It is chiefly due to maturity at time of harvest that yield of processed product from Southern grown potatoes is lower than from potatoes grown in the North and harvested at a more mature stage (see also p. 96).

Use of mature tubers usually results in a higher quality processed product, increase in yield of processed product, increase in food value per pound of raw stock as well as in yield of product per acre. Immature potatoes are likely to develop a yellowish coloration during the early stages of dehydration. This coloration is thought to be due to carotenoids. There is no diffusion of this pigment into water such as occurs with the pigment of overheated dehydrated potatoes.

The low yields and absence of highest quality in dehydrated potatoes from immature stock indicate that such material is undesirable and that potatoes to be processed should be allowed to become fully mature before digging. This is true especially if the potatoes are to be stored very long before processing. In order for tubers to attain as great a degree of maturity as possible and to reach maximum dry matter content, harvest should be delayed as long as feasible without subjecting them to low temperatures. Potatoes should not be chilled in the field before or during digging or in transit to storage. Low temperatures which would not lower the quality of potatoes for home or restaurant use may render them worthless to the processor. It is sometimes necessary to compromise between gaining a few days extra maturity on the one hand and delaying digging so long that the potatoes are exposed to low temperatures resulting in lower processing quality. Potatoes for processing should never be exposed to temperatures below 40°; 45°F. would be better. It is well to know the day and night temperatures in potato fields during the last several weeks before harvest as well as during the harvest period.

CULTURAL AND ENVIRONMENTAL FACTORS AFFECTING DISCOLORATION IN POTATO PRODUCTS

There are three distinct types of discoloration in potatoes as a result of certain physiological conditions and subsequent chemical reactions. These are: (1) discoloration of peeled, cut or injured raw potatoes, (2) after-cooking darkening and (3) the non-enzymatic browning reaction

which usually takes place at high temperatures in the preparation of chips, French fries or dehydrated potatoes.

Discoloration of raw potatoes is a result of enzymatic oxidation in injured cells when they are exposed for a short time to air or oxygen. This type of discoloration is of commercial importance primarily to those in the potato prepeeling business. Causes of this discoloration and methods of preventing it will be discussed in the chapter on "Prepeeled Potatoes" and will not be dealt with here.

AFTER-COOKING DARKENING

One of the most widespread undesirable qualities of potatoes is the tendency for the tubers to turn dark after cooking. It appears first and to the greatest degree just under the skin at the stem end of the potato and decreases in intensity toward the apical end. The color may range from normal white of the unaffected tubers through shades of gray to almost black. It greatly detracts from the appearance of the cooked potato and renders it much less desirable for food. It has no known effect on flavor or nutritive value of the potato. Since many food products are accepted or rejected on the basis of color and appearance this defect undoubtedly has had a marked effect on the gradual decrease in potato consumption. It has been reported from practically every potato growing area in the world and has been the subject of investigation for over 50 years. In the processing field this type of discoloration is especially noticeable in canned, prepeeled and reconstituted dehydrated products.

Growing Conditions and Darkening

(1) **Effect of Fertilizers.**—Many years ago it was reported that potatoes grown with a suboptimum supply of potassium would darken while those with potassium added remained white. Sulphate forms of potassium have been found to be better than the chloride or kainite forms for preventing discoloration. Addition of potassium, which decreases the amount of nitrogen in the potato, also tends to decrease darkening. The content of nitrogen and potassium in tubers is closely related to the amounts of these substances which were added to the soil. Hansen (1935) believes there is no direct connection between the content of potassium and darkening although darkening increases with the content of non-protein nitrogen compounds. Several investigators have shown that addition of nitrogen fertilizer in connection with lack of potassium, in other words a large N/K ratio, increases the tendency to darken.

Wallace and Wain (1943) showed that lack of phosphoric acid results in darkening and that it is connected with the content of iron; with low phosphoric acid or a lack of potassium, iron accumulates in the tubers.

According to Tedin *et al.* (1943) darkening is associated with high content of protein and low amide nitrogen in tubers.

(2) **Soil.**—Reaction of the soil has an influence on the tendency of potatoes to darken; low pH soil is likely to increase darkening. Potatoes grown in muck soils seldom darken whereas those grown in the same area in mineral soils tend to discolor. These differences, however, are due to differences in maturity of tubers and other factors that usually are associated with these soils (Smith 1937 and 1940; Smith and Nash 1940, and 1941).

(3) **Temperature.**—There is a relation between darkening of potatoes and temperatures during the growing season, especially during the last several weeks of growth. Smith and Nash (1942) and Smith *et al.* (1942) showed that potatoes which were still alive and functioning for the last several weeks at temperatures under 50°F., had a much greater tendency to darken than those ripening at temperatures above 60°F. This is the primary reason for most potatoes harvested late to darken more than those which were harvested earlier when temperatures were higher. As further proof of this theory potatoes were harvested in Florida on April 10 and May 15 and the potatoes which were the least mature, but were harvested during the cooler weather, showed the greatest amount of darkening. Potatoes from plants which have been killed early with chemicals also darken to a lesser extent than those killed later.

(4) **Soil Moisture and Light.**—Plants which are irrigated and heavily fertilized produce tubers with greater tendency to darken than plants which receive only normal rainfall. There is a higher degree of darkening in wet, cloudy summers than in dry, sunny seasons (McIntosh 1942). Shading plant increases the darkening of tubers (Nash and Smith 1940; Smith and Nash 1941).

Probably neither of the factors, light intensity nor soil moisture, directly affects the darkening tendencies. For instance, if soil moisture is low and it reduces the availability and absorption of certain fertilizer elements such as nitrogen or potassium it may decrease the prevalence of darkening by hastening maturity at a time when temperatures are relatively high. On the other hand, soil moisture may be high but the soil fertility very low and relatively little nitrogen or potash available, resulting in early maturity, during warm weather, and resultant decrease in darkening.

Varietal Differences.—Some European workers believe that there are no pronounced differences between varieties in their tendency to darken (Hansen 1935; Parker, 1932). Nash (1941), however, found marked differences in darkening between varieties grown under the same environmental conditions. In breeding experiments Rieman *et al.* (1944) crossed plants of white-boiling with those of dark-boiling potatoes and found that

the tendency to remain white after boiling was totally or partially dominant.

Causes of After-Cooking Darkening

Some investigators have assumed that the discoloration is a result of the tyrosine-tyrosinase-melanin reaction. As early as 1905, however, it was shown that there could be no connection between darkening and tyrosinase activity (Ashby 1905). Later workers (Merkenschlager 1929A and 1929B, and Tinkler 1931) state that tyrosinase could be active in this reaction during the short time before the cooking water reaches the boiling point. Oxidation is necessary for the formation of the dark pigment. It is assumed that the potato tissue contains sufficient oxygen for the initial stages of the reaction but atmospheric oxygen is necessary for the final steps in oxidation. Boiling potatoes in water while exposed to a nitrogen atmosphere does not decrease the tendency to darken although those exposed to nitrogen after boiling do not discolor (Nutting and Pfund 1942). The potato cell organization is destroyed at 131°F. and tyrosinase is inactivated at 158°F. so that the reaction may take place between these two temperatures, Hansen (1935).

According to Tinkler (1931) iron in the tubers increases darkening either by a catalytic action or the result of formation of an iron-phenol compound which is dark colored.

(1) **Iron Content of Potatoes.**—The iron content varies between 2.5 and 10.5 mg. per 100 grams dry substance. Little is known of the form in which iron is found in the potato. Shackleton and McCance (1936) report that 90 to 100 per cent of the iron is found in inorganic compounds and Shive (1941) is of the opinion that the major part is found in insoluble form, most likely in the form of precipitated organic ferric complexes. There probably is an equilibrium between ferrous ions and ferric ions, of which the ferrous ions are physiologically active.

That the darkening does not take place until after boiling must be due to the fact that ferric ions are not present in the potato when the cell organization is destroyed, as otherwise these ions, in spite of the presence of ascorbic acid, would form the dark colored iron-diphenol compound before the air was admitted. The ferric ions must, therefore, be present in an insoluble state or, at least, they are precipitated during the heating.

There is disagreement among the different investigators as to the influence of iron on darkening, but this may be due to the fact that in most cases the content of iron is determined while the important thing is the content of the free ferrous ions. Furthermore, the variations in content of iron may be so small that other factors which influence darkening conceal the influence of the iron. These might be such factors as hydro-

gen ion concentration or the ratio between the concentrations of o-diphenol and other complex formers.

If we assume that the darkening is due to the production of an iron-o-diphenol compound it should be expected that variations in the amount of ferrous ions present will influence the degree of darkening and certain circumstances point in that direction.

(2) **Ortho-diphenol Content of Potatoes.**—It is believed that the o-diphenol compounds are predecessors of the pigment that causes darkening of potatoes and that the pigment is formed by oxidation. Smith *et al.* (1942) found that darkening was produced by boiling potatoes in a solution of potassium bromate, an oxidizing agent, whereas a solution of stannous oxalate, a reducing agent, prevented darkening. The most complete investigation in this field has been done by Juul (1949). He found that caffeic acid and chlorogenic acid are present in the potato in approximately the same molar concentration. They form the major part of the o-diphenol content of the potato. He also found higher amounts of o-diphenol in the basal than in the apical ends of tubers although the differences were not always considered significant statistically.

It has been shown that darkening is worse in plants that are heavily fertilized with nitrogen. o-Diphenol content also usually is higher in tubers from plants which receive large applications of nitrogen as compared with those with less nitrogen or with a low N/K ratio.

Darkening usually is less in immature than in mature tubers. However, no consistent correlation has been found between o-diphenol content of basal ends of tubers harvested at different stages of maturity and color of the boiled potato.

Ross *et al.* (1939) found a high correlation between the o-diphenol content of tubers and darkening after boiling.

(3) **Effect of pH of Tuber Tissue.**—This discoloration always appears first and to the greatest extent and, in most cases, exclusively, in the stem ends of tubers. Likewise the pH values of the stem ends of potatoes are higher than those of the apical portion. Potatoes boiled in acidulated water remain white rather than turning dark.

Smith *et al.* (1942) showed that darkening depends on hydrogen ion concentration. By boiling potatoes in solutions ranging from pH 3 to 9 it was found that darkening could be prevented in solutions more acid than the normal potato and intensified at reactions more alkaline than that of normal potatoes. The pH of tubers also was changed by storing them at high temperatures for a short time or by storing them in various gas mixtures. Any storage treatment which resulted in decreased pH of the tubers also decreased or prevented darkening. At high temperatures (100°F.) or in inert gas (nitrogen) anaerobic oxidation is increased.

This results in the formation and accumulation of organic acids which lower the pH of the tubers. Because of the low supply of oxygen in these tissues the o-diphenol compounds may be present in the reduced form and further oxidation to dark colored compounds would be unlikely. Results obtained by Smith and Kelly (1944A) with potatoes treated with ethylene chlorohydrin to greatly increase respiration rate, followed by storage in various gases at several temperatures showed, however, that there is not a perfect relationship between pH of the tuber and appearance of blackening, without regard to the method of changing the pH of the tuber.

The pH of the potato increases with the degree of ripeness (Juul 1949). Juice from dark boiling potatoes has a higher pH than juice from those which remain white. The hydrogen ion concentration of boiled potatoes is between pH 5.7 and 6.4. In the raw potato the pH is lower because of the presence of CO_2 in the juice.

(4) **Importance of Iron and o-Diphenol Compounds in Blackening.**—It is believed that an iron compound in the potato is involved in the reaction which results in after-cooking darkening. Juul (1949) found that the violet ferric-dipyrocatechol compound may be decolored by pyrophosphate. Pyrophosphate also repressed the darkening in potatoes. Potatoes which have darkened after boiling may be restored to a white color by placing them in a pyrophosphate solution for some time. Smith (1957B) treated unpeeled whole potatoes by dipping them in a solution of sodium acid pyrophosphate and also by vaporizing the chemical in the air surrounding the potatoes. After 48 hours in a tight container, treated potatoes showed little or no darkening after boiling, whereas, untreated potatoes exhibited it to a great extent. This probably results in the formation of colorless iron-pyrophosphate complexes and a consequent white potato.

Prevention of After-cooking Darkening

The most logical theory of the cause of after-cooking darkening appears to be the reaction of certain types of o-diphenols and certain forms of iron. The ferrous ions of the tuber combine with an o-diphenol giving a colorless or faintly colored compound. This compound oxidizes when exposed to air forming the deeply colored ferric compound. Ethylenediamine tetraacetic acid (EDTA) and its salts chelate iron preferentially to all other commonly occurring metals. Smith and Muneta (1954) and Greig and Smith (1955) reduced or prevented after-cooking blackening by spraying chelating chemicals on plants in the field and by dipping peeled potatoes in dilute solutions 24 hours or more before boiling. Other chemicals such as gluconic acid, citric acid, sodium gluconate, sodium citrate,

ammonium gluconate and sodium bisulfite also reduced after-cooking darkening when applied as a spray to foliage in the field. It is believed that in most instances these chemicals have reduced darkening by sequestering or chelating the iron in the tubers so that it is held in a non-ionizable form and cannot take part in a reaction with o-diphenol and, therefore, prevents the normal formation of the dark colored pigment, a ferric o-diphenol compound.

Smith (1957B and 1958A) prevented the appearance of after-cooking darkening by treating whole unpeeled tubers with sulfur dioxide gas for 24 hours. Two minute dip treatments with the following chemical solutions previous to 24-hour storage of potatoes in tight containers resulted in little or no darkening after cooking: sodium bisulfite, sodium gluconate, sodium acid pyrophosphate and the trisodium salt of N-hydroxyethylethylenediaminetriacetic acid. The latter chemical forms ferric chelates with the trivalent or ferric iron ions.

DISCOLORATION OF CHIPS, FRENCH FRIES AND DEHYDRATED POTATOES

Varietal Differences

Some varieties consistently produce lighter, more attractive appearing processed products than others. Varieties which process into light chips also usually result in light French fries and bright colored dehydrated potatoes. Results of numerous experiments conducted in many potato producing areas of the country show that the varieties best adapted to processing into light-colored products are the following: Russet Burbank, Russet Rural, Irish Cobbler, White Rural, Kennebec, Sebago, Katahdin, Cherokee, Chippewa and White Rose. Some of these varieties are usually low in specific gravity and, therefore, are not highly desirable because of low yields of product or poor texture of finished product. Other rather new varieties which produce attractive processed products are Delus, Merrimack, Saco and Plymouth.

Shallenberger (1955) found that Kennebec and Russet Rural tubers produced lighter colored chips than tubers of Katahdin and Green Mountain. Variation in chip color of varieties was not in direct relation to concentration of any of the chemical constituents in the potatoes. The closest relationship, however, is between sugar content of tubers and chip color.

In dehydration tests Cruess and Mackinney (1943) rated the Russet Burbank and White Rose varieties most desirable in color after drying seven varieties. Less desirably colored product was obtained from Houma, Sebago, Chippewa, Sequoia and Bliss Triumph potatoes.

Cultural Methods and Environment

In general the cultural and environmental factors that result in potatoes of high specific gravity also tend to produce potatoes which process into light attractive products.

The most important factors which affect color of processed potatoes are those which influence the maturity of the potato at time of harvest. Maturity is affected by time of planting, soil moisture, location, mineral nutrition, temperature during the growing season, degree of control of insects and diseases, time and method of killing vines and time of harvest.

It has been well established that color of dehydrated immature potatoes is not as attractive as that produced from tubers more mature at time of harvest. Practically all immature potatoes develop some degree of yellowish coloration during the earlier stages of drying. This yellowing probably is due to a factor inherent in the material, to the presence of constituents, possibly carotenoid in nature (Caldwell *et al.* 1944). This type of discoloration apparently is not related to the darkening of dehydrated potatoes as a result of high reducing sugar content of the raw stock.

The reducing sugar content of raw potatoes has a very marked effect on the ease with which they can be dehydrated without discoloring during dehydration or subsequent storage. Potatoes with high reducing sugar content are more likely to scorch or discolor during dehydration and to turn dark during storage. Bedford (1946) found that reducing sugar content of freshly harvested Washington grown potatoes varied from 0.80 to 2.03 per cent on the dry weight basis. Stamberg and McKinnon (1946) obtained an average reducing sugar content of 2.7 per cent in 108 freshly harvested samples of potatoes grown in Idaho.

In addition to reducing sugar content of raw potatoes, the browning of dehydrated potatoes is also related to the content of certain nitrogen fractions. Doty *et al.* (1946) found a definite correlation between the amount of amino nitrogen present in mature raw tubers and the amount of browning which occurred during dehydration, but the amount of reducing sugars present was not closely correlated with the browning.

Mature tubers usually produce lighter colored chips than those harvested at a less mature stage. These differences are especially marked after several months storage at 40° to 45°F. or lower. Reducing sugar content of potatoes, in general, is closely related to the color of chips made from them (Smith 1955 and 1956; Shallenberger 1955).

Effect of Chemical Weed Control on Processing Quality of Potatoes

In some potato growing areas it is the practice to control weeds early in the season with the application of certain chemicals to the soil. These

chemicals usually are applied as sprays to the soil before the potatoes emerge, but after many weed seeds have germinated and are in the seedling stage. This is referred to as pre-emergence application. Any chemical properly used which injures the potato plant, reducing yields or which detracts from the quality of the processed product should not be recommended.

During the past twelve years, good weed control has been obtained in potatoes by applying one of several of the group of chemicals known as the dinitro compounds. Examples of these are dinitro-o-secondary butyl phenol and dinitro-o-secondary amyl phenol which are available under the trade names of Premerge and Sinox PE. When these are sprayed uniformly on the potato field from 14 to 21 days after planting, before potatoes emerge, at the rate of three pounds actual chemical to the acre, good control of weeds usually results. Under these conditions there is no injury to the potatoes and no alteration in yields or dry matter content of the tubers. Potatoes from treated and untreated areas have been made into chips and no off-flavors nor any effect on color or keeping quality of the chips have been detected (Smith 1954).

Effect of Insecticides on Flavor of Potatoes and Potato Products

There are several insects that live in the soil for a portion of their life cycle and which cause considerable damage to the tubers. The Eastern field wireworm and the wheat wireworm are very troublesome in certain areas, boring into the tubers and rendering them of very low quality for processing. One of the early insecticides used for the control of these insects was benzene hexachloride. Later, lindane was used for this purpose. Both of these chemicals, however, are likely to impart an off-flavor, described as "musty," to the potatoes grown in soils in which they have been incorporated. This off-flavor also has been detected in processed products made from potatoes grown in treated soil.

Foliage applications of lindane to potatoes or even to some other crop preceding potatoes has been known to affect the flavor of the succeeding potato crop (Kirkpatrick *et al.* 1955). When lindane was applied to the soil at the rate of one pound per acre the year prior to that in which potatoes were grown, the treated samples were judged off-flavor (Kirkpatrick *et al.* 1951). Further search for insecticides which control wireworms has resulted in the discovery and use of such chemicals as heptachlor, chlordane and dieldrin which, when used properly do not impart an off-flavor to potatoes.

GROWING AND HARVESTING POTATOES

The volume of potato production in the United States fluctuates usually between 350 million and 400 million bushels annually. Of this amount

approximately 75 million bushels or 20 per cent of the total are processed each year. From this it appears that potato processors have a wide choice in the selection of their raw stock. However, much of the annual production is lost by decay and shrinkage in storage, millions of bushels are used to plant the following crop and a large portion of the total production does not possess the desirable characteristics for processing. Most varieties for instance, are not adaptable to processing although they may be highly desirable as table stock. It is necessary that processors exercise great care in the procurement of potatoes that will make a high quality finished product. It also is highly desirable that potato growers be aware of the raw stock requirements of processors and that they attempt to grow, handle and store potatoes so that they will meet these specifications.

Potato Growing Areas

Potatoes are grown commercially in every state of the United States. The potato crop may be classified according to time of harvest as early, intermediate and late. The early crop comprises about 13 per cent of the total production, the intermediate crop about 17 per cent and the late crop approximately 70 per cent. The crop from the early and intermediate areas is consumed within several weeks after harvest whereas two-thirds or more of the late crop is stored for use during winter and spring.

The early crop consists of the winter, early spring and late spring crops and is grown largely in Florida, Alabama, southern California, North Carolina, South Carolina, Louisiana, Tennessee and Texas. Potatoes in these areas are planted from November to the middle of March and harvested during the period January to early July.

The most extensively grown varieties of the early crop that are adaptable to processing are White Rose, Sebago, Irish Cobbler, Kennebec, Russet Sebago, Katahdin, Cherokee, Plymouth and Chippewa.

The intermediate crop is made up of the early summer and late summer harvest and is grown primarily in Virginia, New Jersey, Kentucky, Long Island, New York, Missouri, Maryland and Delaware. Potatoes in these areas are planted in late March and April and harvested mostly in June and July. Leading varieties used for processing are Irish Cobbler, Kennebec, Katahdin, Cherokee, Chippewa and Delus.

The late or main crop is grown in all Northern and Western states. The leading states in production of late crop potatoes are Maine, Idaho, New York, North Dakota, Minnesota, Wisconsin, Michigan, Pennsylvania, Colorado, Washington, Oregon, California, Nebraska and Ohio. Potatoes usually are planted in May and June and harvested in September and October. Principal varieties grown in these areas for processing are

Katahdin, Russet Burbank, Russet Rural, Kennebec, Irish Cobbler, Chippewa, Sebago and Cherokee.

A number of cultural and environmental factors are important in potato production in determining quality of potatoes for processing. These include (1) variety, (2) soils and rotations, (3) time of planting and time of harvest, which largely determine maturity of the tubers, (4) kind and amount of fertilizers applied, (5) rainfall, irrigation and soil moisture, (6) control of insects and diseases and (7) vine killing.

Varieties for Processing

It has been shown earlier that there are a number of varieties suitable for processing. The varieties grown principally in one area or at one season are not necessarily the same as those grown in another area or time of year. Potato growers interested in supplying processors with high quality stock must confine their choice of varieties to those acceptable by that industry. Farmers should grow varieties also which yield well on their soils and under their climatic conditions in order to make it economically possible to compete with other suppliers. Some varieties consistently yield higher than others when grown under similar conditions.

Potatoes of a suitable variety must process into a light-colored product. They must withstand storage so that they will process well not only soon after harvest but for 6 or 8 months afterwards. It is possible for a potato to boil, bake or mash to an attractive white color but be worthless to the processor because of excess darkening during or following processing. Most types of darkening of processed potatoes are a result of high reducing sugar content of the raw stock. Tubers of some varieties are inherently higher in reducing sugars than those of others grown and stored in the same manner. Many of these varieties such as Green Mountain and Pontiac cannot be used for processing because of this factor. Varieties for processing also should be of high specific gravity. Some varieties such as Russet Burbank, Kennebec and Merrimack are consistently higher in specific gravity than varieties such as Chippewa, Early Gem and Ontario when grown under the same conditions.

Soils and Rotations

Type of soil in which potatoes are grown may affect the processing quality of the tubers. From numerous comparisons in areas in many parts of the United States and through a period of years it has been found that higher specific gravity potatoes usually are grown in mineral or upland soil than on muck or peat soils in the same area. Muck grown potatoes of suitable varieties generally result in a light color processed

product but the yield is low and in deep fat fried products, the oil content is high.

Sandy soils usually are of lower moisture content than heavier soils such as loam or clay loam. In a wet season this could be an advantage and result in potatoes of higher specific gravity. In a dry season, however, it may result in lower yields of tubers but they might still be high in specific gravity unless the growing season temperature is very high. A soil high in moisture usually is several degrees cooler than a similar soil of low moisture content. This cooler soil may result in high specific gravity tubers because less plant food is lost from the potatoes by respiration.

Sandy soils can be plowed, prepared and planted early. They are conducive to rapid growth, provided sufficient nutrients and moisture are present and they also result in relatively early maturity of the crops, which is desirable. Heavy soils usually cannot be planted until late in the season, thereby resulting in later growing seasons and delayed maturity. Many good chipping potatoes, however, are grown in heavy, well drained soils.

Soils adapted to potato production are well drained, of loose, friable structure such as sandy, gravelly or shale loams and loams with an ample supply of organic matter and fairly high in fertility. Good yields of potatoes of moderate specific gravity are grown on muck or peat soils. There are muck areas devoted to potato production in Minnesota, Wisconsin, Iowa, Indiana, Ohio, Michigan, New York and California. Soils that are too sandy, that is, with a small proportion of smaller soil particles and especially those low in organic matter, usually are not desirable for growing high yields and good processing quality tubers. They have a low water holding capacity and potatoes grown in them are likely to lack sufficient moisture. Mineral nutrients also are lost extensively by leaching. Heavy, poorly drained clay and clay loam soils are not desirable, especially those with tight clay subsoil. The potato plant responds well in soils which have 50 per cent or more of pore or air space. In many instances less than this amount causes potatoes to yield at a low rate and the tubers often are off-shaped and of low quality.

Because of the likelihood of the prevalence of potato scab, *Streptomyces scabies,* in soils above pH 5.2 it is preferred that potato soils be selected which are between pH 4.8–5.2.

Organic matter content of potato soils is maintained primarily by plowing under plant material from other crops in the rotation. Crop rotations vary from one potato growing area to another so that no general recommendation can be made. In some locations, such as Long Island, it is common for potatoes to be grown continuously every year on the same

area with rye as a cover crop seeded each fall and plowed under the next spring. In other locations, potatoes are grown in 2-, 3-, 4- or 5-year rotations with such crops as small grain, clover or alfalfa. Usually the small grain follows potatoes; the grain is seeded to a legume and is combined. The legume may be plowed under the second spring in a two year rotation or it may be harvested for hay for one, two or three years. Best yields of potatoes are obtained by growing them in the rotation immediately following the legume. Rotations apparently have little direct effect on quality of potatoes for processing.

Length of Growing Period

Potatoes are planted in some area in the United States almost every month of the year. The winter, spring and summer crops usually are harvested at an immature stage and are consumed within a relatively short time after harvest. Although maturity is highly desirable in potatoes for processing, the winter, spring and summer crops are harvested while the plants are still green and immature. Their time of harvest is dependent largely upon expected prices on the market and a time when harvest at one area does not conflict too much with that of one or more other sections. In some instances, however, such as in the potato growing region of Alabama, harvest of potatoes for processing has been delayed beyond the usual period in order to obtain a greater degree of maturity and to supply processors with higher quality raw stock.

The late or main crop in most areas is planted in May or June. Early planting of potatoes for processing is desirable because of the greater opportunity for them to achieve more maturity at time of harvest. Likewise, the season may be extended and a greater degree of maturity obtained by harvesting potatoes late. Growers should be very careful, however, not to delay harvest to such a time that the potatoes will be exposed to temperatures below 40°F. either before, during or after harvest. Although higher specific gravity tubers may be obtained, this will be of no advantage if sugars accumulate during the exposure of tubers to low temperatures. Harvesting in the late potato areas usually is done in September and October.

With most potato varieties and modern methods of growing potatoes, few obtain complete maturity before harvest. To enable the grower to complete his harvest before the advent of low temperature conditions and also to facilitate harvesting operations, most potato vines are killed mechanically or with chemicals several days to a week before harvest. Methods of killing potato vines and their effect on processing quality of the tubers will be presented later.

Kind and Amount of Fertilizer Applied

Potatoes require large quantities of mineral nutrients for maximum growth and yields; particularly large amounts of nitrogen and potassium are utilized by the plants. If any of the mineral nutrients in the soil are available in suboptimum amounts anytime during the season, growth may be stunted, size of tubers may be small and misshapen tubers may be produced. Although there is a supply of available nutrients naturally present in most soils, fertilizer is needed to supplement it to obtain maximum yields and market quality.

The kind and amount of fertilizer required for large yields depends on the type of soil, native state of fertility of the soil, rotation, variety, length of growing season, available moisture and planting distances. In most areas potatoes respond to applications of complete fertilizers, those containing nitrogen, phosphorus and potassium. There are a few locations where application of only one or two of the above nutrients is necessary for maximum yields. For instance, in the potato growing areas of Idaho it has been found that potatoes do not respond to applications of potassium. The soils in that area are high in native potassium and no further additions are needed. Recommendations for fertilizer application in Idaho are for 80 lbs. N, 40 lbs. P_2O_5 and no potash per acre when potatoes follow a row crop in the rotation and 40 lbs. N, 60 lbs. P_2O_5 and no potash when potatoes follow alfalfa. There are some areas in Colorado and southern California also where potatoes do not respond to potash applications. In western Montana greatest yield response is obtained from the application of phosphorus to potato soils.

The ratio of fertilizers for potatoes, the proportion of nitrogen (N), phosphoric acid (P_2O_5) and potash (K_2O), is important. No one ratio is suitable to all soils, areas or varieties. The most widely used and recommended ratios for complete fertilizers are 1-2-1, 1-2-2, 2-3-3, and 1-1-1. Some of the fertilizers corresponding to these ratios are 5-10-5, 6-12-6, 10-20-10, 5-10-10, 8-16-16, 10-20-20, 6-9-9, 8-12-12, 8-8-8 and 10-10-10.

The rate of fertilizer application varies from one potato producing area to another. This depends largely on the state of fertility of the soil, rainfall, length of growing season, variety, spacing and other factors. On any particular farm this can best be determined by field fertilizer experiments supplemented with soil tests for their available nutrient content.

In late potato areas, all fertilizer usually is applied before or at the time of planting. A portion of the fertilizer is sometimes broadcast before plowing and fitting, with the remainder applied on both sides of the row through the planter at time of planting. Others apply all of the fertilizer in bands through the planter. In many early production areas, in addition

to fertilizer applied at planting time, sidedressing applications are made during the growing season. Also in some irrigated areas in the west, additional fertilizers are applied by bleeding them into the irrigation water.

In addition to nitrogen, phosphorus and potassium, many soils are low in magnesium and additions of this element to soils of low pH often result in increased yields of potatoes. In a few muck soils potatoes respond to applications of copper.

Fertilizers applied to potatoes affect their processing quality. Highest dry matter tubers are produced in soils where no fertilizer has been added. This results in low yields, however, and therefore, this practice cannot be recommended. It is suggested, however, that potato growers apply no more fertilizer than is needed to obtain satisfactory yields. Nitrogen and potassium especially have a tendency to produce potatoes with decreased dry matter content. Further discussion of the effect of fertilizers on processing quality of potatoes has been presented earlier in this chapter.

Rainfall, Irrigation and Soil Moisture

The moisture content of soil is one of the most important factors which determines yield as well as processing quality of potatoes. Potatoes respond favorably to an abundant and even supply of soil moisture in growth and yield. An oversupply of moisture or high soil moisture content late in the season may result in low specific gravity tubers and poor processing quality. In humid areas potato growers have no control over their supply of water except that they can supplement normal rainfall with irrigation if it is necessary. In arid and semiarid sections, growers have more control over their moisture supply and may apply as little or as much as needed. It is suggested to potato growers that they do not over-irrigate at any one time and that time between irrigations be rather short to avoid large fluctuations in moisture supply of the soil. Fluctuations in soil moisture tend to promote unequal growth in vines and tubers resulting in lower yields and formation of many misshapen, second growth and growth-crack tubers. It also is suggested that water be withheld late in the season to give potato plants an opportunity to mature and to produce tubers of higher specific gravity.

Control of Insects and Diseases

The control of insects and diseases on potatoes is an important factor affecting yields and quality of tubers. The most common insects which may be controlled by spraying or dusting the plants are Colorado potato beetle, flea beetle, leaf hopper and aphids.

Colorado potato beetles may be controlled by two or three applications of DDT. Early application is essential to kill the first brood that

appears. In areas where this insect has developed resistance to DDT, applications of heptachlor or dieldrin keep it under control. Adult flea beetles are small, black, shiny insects which appear early in the growth of the plants. They eat small, round or irregular shaped holes in the leaves. This insect can be controlled by applications of DDT, heptachlor or dieldrin. The potato leaf hopper is a green wedge-shaped insect about one-eighth inch long. It feeds mainly on the undersides of leaves. As it feeds it secretes a toxic material which causes hopperburn, the tips and margins of leaves become brown and die. Heavily infested plants may die prematurely resulting in low yields and low specific gravity tubers. DDT applications control this insect. Aphids, or plant lice, are green or pink soft-bodied insects about one-sixteenth inch long. They damage potatoes by sucking juices from the foliage and by spreading virus diseases. This insect is controlled by spray applications of parathion or malathion. Best control is obtained by directing the spray towards the undersides of the leaves.

As a result of the high degree of control of insects with modern insecticides such as DDT and others, the life of potato plants is prolonged, they remain green and actively growing and hence, are delayed in maturity. This affects chemical composition of the tubers and the color of processed products made from them. It also tends to retard formation of high dry matter in tubers and, therefore, makes them less desirable for processing. Other phases of this problem are presented in an earlier section.

The most common potato diseases which can be controlled by spray or dust applications to plants are early blight and late blight. Early blight is best controlled by frequent spray applications of nabam-zinc sulfate. Late blight may be controlled by spraying with nabam-zinc sulfate or one of the copper containing materials such as Bordeaux mixture, copper oxychloride sulfate, basic copper sulfate and wettable cuprous oxide. There is very little evidence to indicate that application of any of the fungicides has much influence on processing quality of the tubers. If plants are injured extensively or killed by early or late blight because of inadequate application of fungicides, yields are reduced and tubers of low specific gravity may be produced.

Vine Killing

Proper application of modern insecticides results in such good control of insects that maturing of the vines is delayed until very late in the season. In most late crop areas, plants are killed by frost or by applications of chemicals to the tops or by mechanically removing them. After the vines are killed the tubers continue to grow a thicker periderm or skin and thus are better able to withstand harvesting operations with less injury. Also

if killing is done slowly, such as that following chemical spray applications, some plant foods such as sugars, are translocated from the leaves and stems to the tubers. These are transformed to starch and increase the dry matter content of the tubers. If killing is done rapidly, such as a result of mechanical destruction of the tops, there is no translocation of materials to the tubers and, hence, no increase in dry matter.

Chemical sprays most widely used for killing vines are the di-nitro compounds such as Dowspray 66 Improved and Sinox General and an arsenical such as sodium arsenite. These materials may be applied with the regular potato sprayer covering 4 to 20 rows. A good kill can be obtained with these chemicals in 3 to 10 days depending upon the temperature subsequent to application.

Vines are also killed mechanically by machines such as beaters and cutters of various types. Beaters usually have rubber flails or short pieces of chain mounted on a rapidly rotating cylinder which is suspended just above the soil surface. Proper adjustment of height of the cylinder and length of flails is necessary to prevent uncovering the potatoes or of mechanical injury to them. Some potato growers rotobeat the vines and then apply a chemical vine killer to the short stubs of stems. Others kill the vines with chemicals and then, to facilitate harvesting, remove most of the dead vines mechanically before digging.

All methods of vine killing may tend to produce vascular discoloration in some of the tubers. This may be prevented or reduced by irrigating the soil before harvest or by waiting until rain has increased the moisture content of the soil. Most vascular discoloration is likely to result from the use of vine killers that act the quickest. For best results harvest should be delayed until a week or ten days following killing of the vines.

Harvesting Potatoes

One of the most important operations in potato production is that of harvesting. If this is not done with care the crop may be greatly damaged and severe losses in storage may result. Much of the commercial harvest is done with one-row or two-row mechanical diggers although an increasing acreage each year is handled with mechanical harvesters. Methods of harvesting vary from farm to farm and from one area of the country to another.

Where one- or two-row diggers are employed potatoes usually are dropped to the ground behind the digger and picked up later by hand. Potatoes may be picked into bushel crates, wicker or wire baskets, sacks or other containers. Those picked directly into bushel crates and sacks are loaded onto trucks and transported to the packing shed or storage. In some instances potatoes from any of the above containers may be

dumped into barrels or into bulk body trucks which transport the potatoes to their destination.

There are numerous types of mechanical potato harvesters. Many of them are made by potato growers in their own farm shops. These machines, either of the one-row or two-row type, dig the potatoes, separate them from the soil, vines and stones and deliver the tubers into containers for transit to storage or packing shed.

Courtesy of Red Dot Foods, Inc.

Fig. 21. Mechanically Harvested Potatoes Are Conveyed to a Bulk Body Truck Traveling Parallel to the Harvester

The first portion of the harvesting operation is lifting the tubers from the soil, with complete recovery of all potatoes and with a minimum of cutting of tubers by the digger blade. The soil is removed by conveying the potatoes over a rod-chain which permits the soil to fall through. Excessive agitation without soil on the elevator chain may cause severe tuber injury. In some machines, vines are removed by hand. Several methods of mechanical vine removal have been developed none of which is entirely satisfactory under all digging conditions. Stones and clods may be hand picked from the harvester. Some harvesters separate stones from

the potatoes by an air blast directed through the chain conveyor, others employ a tilted conveyor for this purpose. In some sections potatoes are dug with a two-row digger and dropped into windrows from which they are picked up later with a harvester.

After separation of potatoes from the soil, vines, clods and stones they are delivered to containers for hauling to storage. In some areas sacks or barrels are used for this purpose. When filled, the sack or barrel may be set off on the ground or carried to the end of the row. In the bulk handling method the potatoes are conveyed from the machine into bulk

Courtesy of Granny Goose Foods

FIG. 22. UNLOADING POTATOES INTO HOPPER FROM BULK BODY TRUCK AT PACKING SHED

hopper bodies on trucks or trailers which travel alongside the harvester in the field. Some bulk bodies have a self-unloading conveyor in the bottom. They are equipped with a tail-gate opening through which the potatoes pass and fall onto another conveyor which carries them into the storage house. Other bulk bodies are equipped with a hinged side, which when unhooked and the body tilted sideways allows the potatoes to flow into a hopper from which they are conveyed to the storage or packing shed.

The use of one-ton palletized boxes as potato containers is increasing

Courtesy of Granny Goose Foods

FIG. 23. CAREFULLY LOADING GRADED POTATOES INTO PALLET BOXES FROM CONVEYOR AND ELEVATOR ABOVE TRUCK

rapidly, particularly with potatoes to be processed. At harvest time these boxes may be placed on a flat bottom truck or trailer and filled in the field directly from the mechanical harvester. Power fork lift trucks are used for unloading and stacking the crates at the storage.

Bruising and other mechanical injury of potatoes during harvest often result in excessive rot of the tubers during subsequent storage and reconditioning. Therefore, it is very important that methods of harvesting maintain a low level of injury to tubers. Some suggestions for attaining this are as follows:

(1) Set digger blade deep enough to avoid cutting the tubers.

(2) Maintain the field speed of the digger at 1.5 miles per hour or less.

(3) Maintain the digger chain speed at 150 feet per minute or less.

(4) Operate the digger chain with the raised portion of the link ends on the underside or shield them with belting.

(5) Use rollers or idler wheels instead of kickers if soil conditions permit.

(6) Cover digger chain links with rubber tubing.

(7) Reduce all drops of potatoes to a minimum.

(8) Where possible, pad all surfaces onto which potatoes drop. Rubber padding and sponge rubber are suggested for this.

(9) Maintain transfer or elevator chain speeds at 70 feet per minute or less.

(10) Place rubber tubing on all elevator and piler chains.

(11) Handle potatoes carefully at all times.

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W. J. Hooker

Tuber Diseases

Diseases of the potato influence plant vigor, yield, and storage quality of the tubers. This chapter is intended to serve as a guide for identification of the various tuber diseases and to provide an understanding of factors influencing severity of disease, rate of spread in transit and in storage, and incidence of disease within a population of potato plants or potato plant parts. It is important that a disease be understood as an interaction between the potato plant (suscept or host) and the disease inciting organism (causal organism), under suitable environmental conditions. The severity of this interaction is determined by inherent resistance of the suscept and the pathogenicity of the incitant, both of which are influenced by limitations of environmental factors, a few of which are temperature, aeration and humidity.

The tuber is a living plant part considered to be dormant, at least in certain respects. Degree of dormancy, rate of tuber respiration, ability for wound healing, and chemical composition of the tubers are factors influencing the spread of disease inciting organisms through the tuber tissue as well as incidence of rot in the tuber population.

Emphasis is placed on the more commonly encountered diseases of potato particularly those influencing quality, appearance, and storage properties of the tuber. Infrequently observed tuber diseases, those of local occurrence, and disorders influencing only vine symptoms and yield will not be included. The reader is referred to the literature cited for additional details concerning methods of control, factors influencing disease expression, and spread of disease in the field. Where possible, the more recent references are cited to permit greater ease of searching the literature. Certain general references on potato diseases are of value. These will not be cited specifically for each disease discussed in detail in this chapter.

DISEASES OF NON-PARASITIC ORIGIN

Low-temperature Injury

A number of different types of frost injury are commonly encountered. The type of injury is influenced by the temperature to which tubers are

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exposed and the time of exposure. Types of low temperature injury to potato tubers range from outright freezing of the tissue through black discoloration of more susceptible tissues, to mahogany browning. Tuber tissues which are completely frozen are killed and upon thawing break down in a rapidly developing watery rot in which soft rots of various types may be involved. In dry air, frozen tissue may be dehydrated producing a granular, chalky type of rot.

If exposure to low temperature is of short duration or if temperatures are not far below the freezing point, injury may be less extreme involving chiefly the more susceptible tissues (Jones *et al.* 1919). Symptoms are variable. The net necrosis type of injury consists of a blackening of the vascular elements throughout the tuber producing a net-like appearance in a cut section. This may grade into a ring type of disorder in which

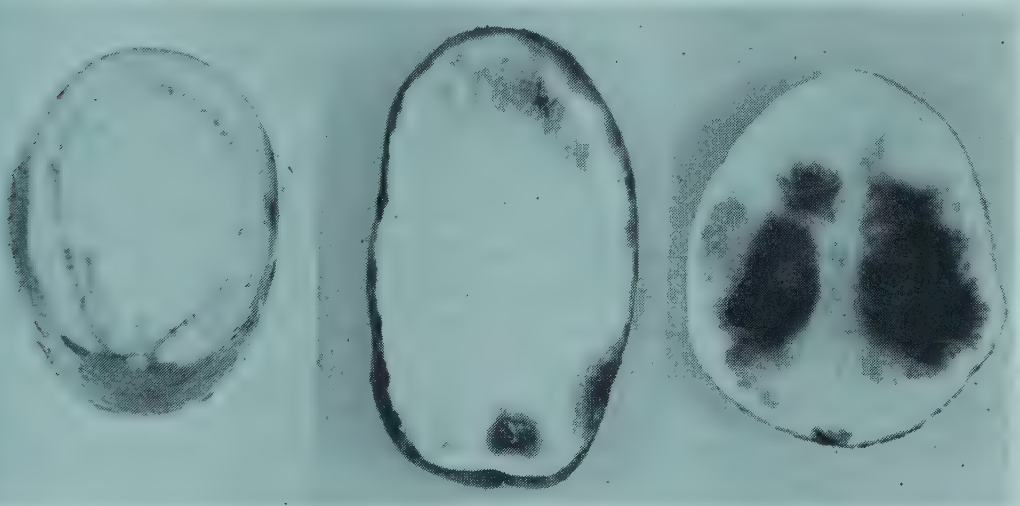

FIG. 24. LOW TEMPERATURE INJURY OF THE NET NECROSIS TYPE (LEFT) AND OF MAHOGANY BROWNING (CENTER AND RIGHT)

the blackened tissue is most severe in the region of the vascular ring. Injury in this area is often restricted to or is more severe near the stem end of the tuber. A more severe blotch type of necrosis may develop in the cortex, vascular ring, or in the pith. Cortical lesions may extend to the skin. Skin necrosis following frost injury occurs in certain thin skinned varieties.

The term, **mahogany browning,** has been applied when tubers are injured at temperatures above 32°F. under conditions in which the tissue is not actually frozen. Symptoms are reddish brown, diffuse areas in the cortex, vascular ring, and occasionally in the pith of affected tubers (Hilborn and Bonde 1942). The disorder develops after long exposure to temperatures in storage at 32°F. or slightly above and becomes severe

toward the end of the storage period. Symptoms are modified when virus leaf roll also is present. Fluorescence of mahogany browned tissue in ultra-violet light is greenish whereas that of typically frozen tubers is bluish. The Katahdin and Chippewa varieties are susceptible while Green Mountain and Warba are highly resistant (Richardson and Phillips 1949). Affected tubers turn black when cooked or when allowed to stand after cooking.

Chilled or frozen tubers, although they may not actually break down with soft rot, are generally more susceptible to soft rot than properly stored tubers. Often such tubers have a sweet flavor following low temperature storage. This flavor may disappear after storage for a short time at higher temperatures.

Tuber tissue is more severely injured when exposed to rapidly diminishing temperatures than when temperatures are slowly reduced. Potatoes may be cooled to several degrees below freezing and warmed without injury providing they are not moved nor roughly handled (Wright and Taylor 1921).

Blackheart symptoms develop in tubers with an inadequate oxygen supply. They consist of clearly defined areas of blackened tissue usually situated toward the center of affected tubers. This tissue is at first firm and later may dry out forming cavities. Soon after injury, blackheart tubers may show little discoloration when cut. Such tissues rapidly turn pink through tan, brown to black. The disorder has been produced experimentally (Bartholomew 1915; Stewart and Mix 1917; Bennett and Bartholomew 1924) over a wide range of temperatures. Exclusion of oxygen enhances speed of development and an adequate oxygen supply precludes blackheart. Singh and Mathur (1938) observed greatest susceptibility in tubers which had been held in storage for some time whereas immature or freshly harvested tubers were relatively more resistant. The larger tubers were more severely affected than the smaller ones.

Physiological internal necrosis of potato tubers is important in the north central states. The disorder is to be expected in other areas where potatoes are produced in soils which become warm especially toward the end of the growing season. The disease has been studied in detail by Larson and Albert (1945 and 1949). Symptoms vary from a light brown rust-colored flecking of the internal tuber tissue to a well defined necrotic area, dark brown in color. Severely affected tubers may resemble to some extent those affected with blackheart. Flecks may coalesce to produce rather extensive areas of discoloration. Affected tissue is firm and does not break down with soft rot. The disease occurs in severity in potatoes grown on light sandy soil. It also is a problem in muck areas especially in certain seasons. Factors influencing the development of the

FIG. 25. INTERNAL HEAT NECROSIS (LEFT AND CENTER)—HOLLOW HEART (RIGHT)

disease are probably conditions similar to those predisposing tubers to blackheart. Of the commonly grown varieties, Triumph, Red Warba, and Kennebec are resistant. Sebago and Irish Cobbler are intermediate, whereas Katahdin, Russet Rural and Ontario are very susceptible. Friedman (1950) observed no increase in disease severity in stored potatoes over a period of 143 days as compared to disease incidence at harvest. Internal tuber discoloration of similar appearance often follows virus yellow dwarf infection.

Hollow heart develops usually in the center of large tubers producing a cavity with little discoloration of the surrounding tissue. Tissue lining the cavity may be uncolored or a light tan. The cavity is apparently formed by a splitting of the tissue during rapid growth of the tuber. Krantz and Lana (1942) indicate that the breakdown ultimately developing in hollow heart had its inception during the initial development of the tubers or shortly thereafter. Levitt (1942) reasoned from histological studies that causal factors predisposing tubers to hollow heart are determining influences early in the season.

BACTERIAL SOFT ROT AND BLACKLEG

Bacterial soft rot and blackleg of potato incited by *Erwinia carotovora* probably is one of the most commonly encountered disorders of the potato and the disease is present in practically all potato growing areas of the world. Soft rot attacks tubers in any stage of development and in planted seed tubers, spreading from the latter into the growing plant producing the blackleg symptom. Soft rot commonly develops in combination with other disorders, generally growing in diseased tissue attacked by more aggressive invaders such as the pathogens inciting late blight, ring rot,

Fusarium tuber rot, etc., or in tissue damaged or impaired by high temperatures, low temperatures, suboxidation or bruising.

Tuber bacterial soft rot is well described by Smith and Ramsey (1947) and by Ruehle (1940). In early stages of infection affected tissue is white to cream colored, soft, and watery. A clear watery liquid is often present in freshly cut affected tissue. The boundary between diseased and healthy tissue is usually well defined by differences in texture and firmness. Upon exposure to air and desiccation, rotted tissue usually turns dark, later becomes slimy and may dry to a somewhat brownish chalky mass. Most decay is accompanied by a strong, unpleasant odor. In advanced cases, rotted tissue is often stringy, slimy, and mucous. When viewed beneath the tuber skin, soft rot tissue is first watersoaked and somewhat translucent. The margin between diseased and healthy tissue may later become defined by a dark brownish black band.

Soft rot infection is established through wounds, bruises, natural openings such as lenticels, and less frequently through the stolon attachment. The disease generally is present in advanced stages of infection by ring rot, late blight, or other diseases.

Lenticel infection is particularly important in early harvested, immature tubers which may have been grown in heavy, moist soil. Areas of infected lenticels may, in the early stages, be somewhat raised. Later the diseased tissue spreads out from the lenticel producing a circular lesion which may be somewhat sunken. In cross section, the lesion is more or less semicircular. Multiple lenticel infection produces irregular blotchy areas. Lenticel infection is encountered commonly in tubers which have been washed, incompletely dried prior to bagging, and subsequently stored without adequate refrigeration.

Soft rot may spread in storage from infected tubers to healthy tubers under suitable environmental conditions. Bacterial soft rot following invasion through the stolon generally progresses toward the tuber center. In the early stages, the only external evidence of infection may be a depression near the stolon attachment.

Vine symptoms commonly called blackleg (Leach 1931; Bonde 1950) result from soft rot of the seed tuber. The bacteria migrate from the seed piece to the stem of the potato plant. A toxic substance apparently is produced which causes above ground portions of the plant to turn yellow. Usually the plant assumes a rather erect habit of growth. Leaves become yellow first at the margins and later roll and dry. The lower stem develops a wet, slimy cortical and/or pith rot. Affected cortical tissue often is black but may grade into a light tan color. Xylem tissue turns brown to brownish black. Collapse of the lower stem is followed by premature death of the plant. Tubers produced the current season from blackleg

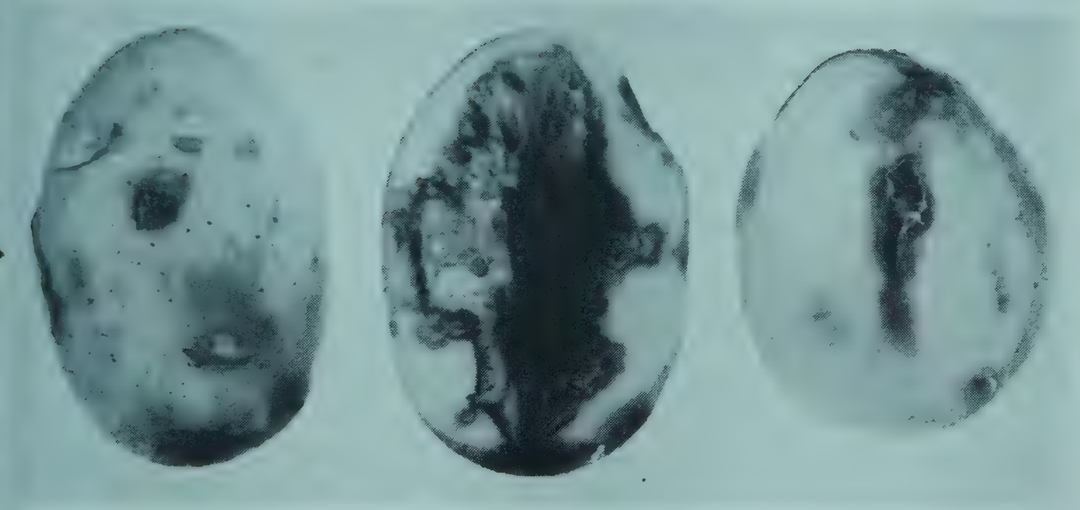

FIG. 26. BACTERIAL SOFT ROT OF TUBERS

External view (left) of tuber in center. Black leg vine symptoms were severe in the field.

infected plants are often rotted following migration of the bacteria through the stolon into the tuber.

Jones (1909) demonstrated enzyme production by *E. carotovora* and described the action of this enzyme on carrot tissue in considerable detail. Pectin dissolving enzymes destroy the middle lamellae of the cell walls in parenchymatous tissue. When exposed to the pectic enzymes, the middle lamellae first swell and the refractive appearance becomes less evident. The cell wall may become twice its former thickness and within a short time delicate laminated structures are evident in the thickened walls. At the same time, the walls lose their refractive appearance. Where the middle lamella is thicker at the angles of the cells, the wedge-shaped masses are last to dissolve. Cells later become separated from each other. Exosmosis of cell fluids, resulting in death of the cell, occurs during the process and rot of tissue progresses very rapidly.

Erwinia carotovora (Jones) Holland is rod shaped 0.7–0.8 $\times$ 1.5–5.0 microns, gram negative, actively motile with peritrichous flagella. It is a facultative anaerobe producing acid and gas in certain substrates. Synonyms are listed by Leach (1931) as *Bacillus carotovorus, Erwinia atroseptica, Bacillus atrosepticus, Erwinia phytophthora, Bacillus phytophthorus, Bacillus melanogenes, Erwinia solanisapra, Bacillus solanisanprus* and others.

The organism is almost universally present in the soil. Furthermore, it is capable of attacking a wide range of plants and is usually most severe on parenchymatous storage organs.

Host reaction of potato to invasion is first a suberin formation evident

as a thickening of the cell walls at the advancing edge of the rot. Periderm layers are later formed beneath the suberized tissue. The histology of lenticel invasion has been well described by Smith and Ramsey (1947). Wound healing processes in response to soft rot invasion are influenced by temperature, aeration, and relative humidity (Leach 1930; Smith and Smart 1955; Rudd Jones and Dowson 1950). The organism, once it has become established in the vascular tissue of the tuber, may be somewhat systemic particularly in the potato seed piece (Leach 1931). Given satisfactory conditions for cork development, the bacteria are confined to the vascular tissue by formation of successive layers of cork.

For proper storage, a balance of temperature and humidity should be maintained sufficiently high to favor suberin formation and eventually periderm formation but yet sufficiently low to inhibit excessive multiplication of bacteria (Rudd Jones and Dowson 1950).

Rapid cooling of tubers immediately after harvest may predispose tubers to decay after removal to higher temperatures even though the incidence of decay may have been very low during refrigerated storage. Smith and Smart (1955) determined the influence of temperature on rate of periderm and suberin development and the effectiveness of these barriers to soft rot invasion. Tubers stored at 70° or 80°F. developed protective suberin and periderm more rapidly than did tubers stored at lower temperatures. This was an important factor in soft rot of potatoes following refrigerated storage and transit. They propose a storage period of 4 to 5 days at 55° to 60°F. to permit wound healing before placing tubers in cold storage.

Predisposition of potato tubers to bacterial soft rot in storage and transit often follows exposure to sublethal temperatures during harvest. Soft rot following predisposition by heat is more severe on freshly dug potatoes than on tubers harvested a few days previously. Furthermore, under experimental conditions approximating solar irradiation (Rose and Schomer 1944), differences between air temperature and tuber surface temperatures were considerable. Discoloration of tuber tissue and oozing from lenticels were present in a few tubers that reached temperatures of 115°–125°F. Soft rot infection normally occurs through wounds associated with normal harvesting and handling operations. Wound healing in potatoes normally prevents infection even though the organism may have been present in the wound. Nielsen (1946) reports that tubers exposed to solar irradiation for as little as 60 minutes in June and July developed more soft rot than tubers picked up and packed immediately after digging. If tuber temperatures rose to 113°F. or higher, tubers with no symptoms of injury rotted at temperatures lower than those usually considered favorable for soft rot development. The thermal death

point of tuber tissue for 1 hour or longer was 122° F. Predisposition to soft rot infection by solar irradiation is a reversible reaction from which tubers are capable of recovery.

Differences in varietal resistance to soft rot injury have been associated with the ability of a variety for rapid wound healing. It is doubtful if these differences are sufficient to be of general use in potato handling and storage operations.

Control of soft rot is best accomplished by avoiding injury to tubers by other diseases and rough handling, and by avoiding injury from adverse storage conditions such as extremes of temperature and humidity. Wound healing of tubers is an important natural defense reaction. Proper conditions of storage permitting adequate wound healing should be maintained for a short time after the crop has been handled extensively. Tubers should be harvested promptly after digging to avoid solar heat injury. Proper drying conditions after washing operations are important in preventing loss resulting from lenticel invasion.

BACTERIAL RING ROT

Bacterial ring rot of potato is incited by *Corynebacterium sepedonicum* (Spieck. and Kott.) Skap. and Burk. The term, bacterial ring rot, is preferable to other names which have been applied to the disease such as bacterial wilt, bacterial blight, bacterial wilt and rot, or bacterial wilt and soft rot. The organism was first accurately described in Germany in 1914 and identified in this hemisphere in 1931 in Canada. At present it is known in all of the major potato producing areas of Canada and the United States. Bacterial ring rot is important as a tuber rot in both field and storage. Because of its highly infectious nature it is one of the major problems in maintenance and production of certified seed stocks.

Tuber symptoms often are obscured by soft rot invasion which generally follows ring rot infection. Breakdown of tubers occurs at any time in the growth and storage life of the crop. Tubers may be rotted at harvest time, others may appear healthy but rot later during the storage period. Repeated grading during storage and careful grading during packing does not assure freedom from ring rot in the final pack.

In the absence of soft rot, the vascular tissue of the cut tuber, particularly that near the stolon end may be a straw to lemon yellow color. At this stage, when the tuber is firmly squeezed, tissue from the vascular ring may be forced out of location somewhat as tooth paste is squeezed from a tube. Affected tuber tissue is somewhat granular in texture described as having a cooked appearance. If soft rot is absent, the tissue will not be stringy nor excessively soft or wet. Vascular tissue may later become brown, with the breakdown extending generally toward the

center of the tuber. In advanced infection, tubers may show a cracking of the surface and eventually only a shell of the tuber may remain. When plants are inoculated with pure cultures of *C. sepedonicum* or when inoculum is free from soft rot bacteria, soft rot usually is absent.

There is some evidence that soft rot progresses more rapidly through ring rot infected tubers than when ring rot is absent. Soft rot usually is present in advanced cases of decay due to ring rot infection. Further-

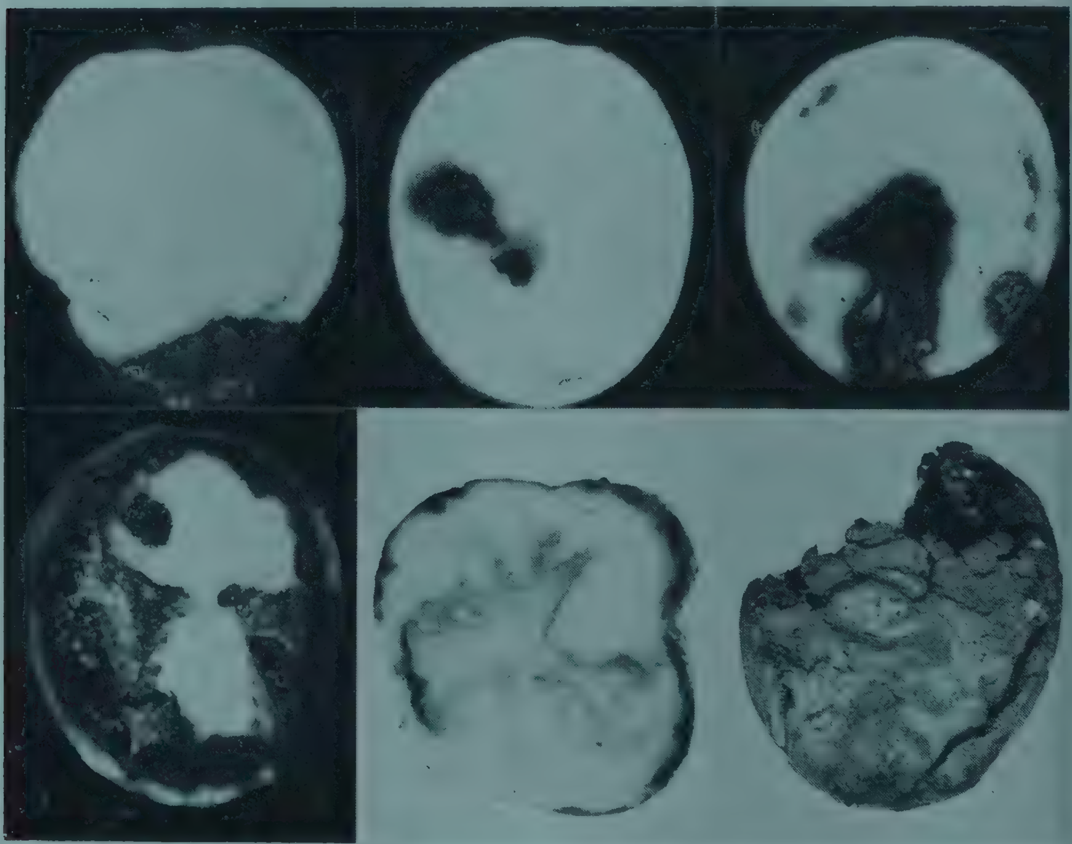

Fig. 27. Bacterial Ring Rot

Symptoms in stored tubers (top row and lower left). Symptoms commonly encountered at harvest (lower center and lower right)..

more, in advanced stages of decay, demonstration of *C. sepedonicum* in rotted tissue may be difficult or impossible. There is also strong circumstantial evidence that the blackleg disease in the field may follow a strong pathogen such as *C. sepedonicum.*

Ring rot and brown rot have somewhat similar symptoms. These symptoms are contrasted in the description of brown rot.

Fluorescence of ring rot infected tuber tissue under ultra-violet light has been used in diagnosis. The greenish fluorescence is associated with increased concentration of riboflavin in infected tissue. Fluorescence is

more reliable as a diagnostic tool at 40°F. than at higher temperatures (Kreutzer and McLean 1943).

Vine symptoms, at first a wilt, generally develop toward the end of the growing season and are first evident on the lower leaves. Wilt often becomes complete either on all stems of a plant or only on a portion of the plant. Wilt of leaflets is soon followed by a chlorotic, somewhat lemon yellow color of the lamina. Leaflet margins become flaccid, may later roll and finally become necrotic. Necrosis develops at the leaf margins and between the veins. Positive identification of ring rot by vine symptoms is extremely difficult if plants have been damaged by early or late blight, Verticillium or Fusarium wilts, black leg, water injury, frost, or insects.

The presence of a watery, white to milky white or cream-colored exudate in the vascular tissue of the lower stem near the seed piece may be demonstrated by pinching the stem between the thumb and a knife blade. Diagnosis is fairly reliable especially if supported by a stained bacteriological smear.

Corynebacterium sepedonicum (Spieckermann and Kotthoff) Skaptason and Burkholder is a short, non-acid fast, gram positive rod, 0.3–0.4 $\times$ 0.8–1.0 micron. Racicot *et al.* (1938) describe an easily used diagnostic gram stain for identifying *C. sepedonicum* in potato preparations. Care should be taken in making bacterial smears to avoid surface contamination of the tissue during removal from the tuber or stem. The organism is slow growing producing small colonies, dull white to cream or light buff in color. *C. sepedonicum* is unable to survive well in competition with other organisms. It is recovered by cultural isolation with difficulty from severely rotted tuber tissue. Also, severely rotted tissue of tubers is relatively low in infectivity when used as inoculum. The bacteria are present largely in the xylem elements of the stem although to a limited extent the bacteria break out into the parenchymatous tissue. In the tuber, the primary tuber symptom of the ring rot disease is disintegration of the principal vascular system associated with the escape of the organism from the vessels into the parenchymatous tissue. This is followed by a necrotic breakdown of the invaded areas, the breakdown may occur over a period of time in storage.

C. sepedonicum is not considered to be soil borne. It overwinters on infected tubers which develop volunteer plants the following season. The chief means of carrying the disease over winter is through infected tubers used as seed. The disease is spread from tuber to tuber through wounds such as bruises in handling operations, contaminated knives during seed cutting, picker planters, diggers, and contaminated bins and storages.

Control is by the use of disease free seed and a vigorous program to avoid contamination of such seed. Bins, crates, warehouses, potato handling equipment, planters, and diggers should be cleaned of debris and surface disinfected with 2 lbs. of copper sulfate per 10 gal. of water or with 1 pint of formaldehyde (commercial 37 per cent) per 5 to 15 gal. of water. Recommendations concerning the concentration of formaldehyde vary between states. After all infected potato stocks have been removed, ring rot free seed stock should be obtained and brought to the farm after the disinfecting operation is complete.

Resistance to ring rot is present in the British variety President and in the American varieties Teton and Merrimack. Although these varieties are highly resistant to the disease they are not considered immune.

BROWN ROT

Brown rot incited by *Pseudomonas solanacearum* E. F. Smith also has been called bacterial wilt, Southern bacterial wilt, bacterial ring disease, and slime disease of potato. *P. solanacearum* has a wide host range on cultivated, wild, and weed plants. It has been reported to be more severe on freshly broken fields than in fields which have been under cultivation for some time. The disease is important in the South Atlantic states from Maryland through Florida and in the Gulf Coast States. It is seldom found in the northern potato producing states and in the central Mississippi Valley. It is common in most tropical and semitropical areas.

Tubers develop dark brown discoloration of the vascular tissue in a rather complete circle. Discoloration may be more pronounced under eyes and at the stolon end of the tuber than in other areas of the vascular tissue. The vascular tissue in these areas may become sufficiently necrotic to be visible from the tuber surface as a greyish brown discoloration. When such tissue is cut, drops of sticky, milky white, bacterial exudate form. Bacterial ooze develops at the stem end and around the eyes of the tuber in soil, often sticking soil to such areas. Cortical tissue of tubers may be destroyed and necrotic tissue extend through to the skin. Tubers rot in soil prior to harvest and continue to rot in storage after harvest.

Vine symptoms are a wilt which is first noticeable at the tips of the stems. Leaves fade to a pale green and finally turn brown without rolling. Epinasty may be evident. This wilt becomes progressively more severe until the stem is permanently wilted and dies. This wilting may not involve all stems of the plant. Vascular bundles of underground portions, stems, roots, and stolons, turn brown. This discoloration may be visible from the surface. Bacterial ooze forms as a white slimy mass on the cut surface of browned vascular tissue.

Brown rot may be confused with ring rot. The chief points of difference are as follows: (1) *P. solanacearum* is gram negative while *C. sepedonicum* is gram positive. (2) Brown rot bacterial exudate is sticky and oozes from affected tissue while ring rot bacteria must usually be squeezed from affected tissue. (3) Vascular discoloration of stem tissue is a very dark brown with brown rot while with ring rot the tissue is usually not noticeably discolored. (4) In the tuber, brown rot discoloration is brown to black with little or no cracking of the tuber skin. In the absence of soft rot, ring rot causes vascular tissue to be less severely discolored and affected tissues are soft, somewhat granular in texture and a light tan to yellow in color.

Pseudomonas solanacearum E. F. Smith is a gram negative rod, 0.5–0.6 × 0.8–1.2 microns, with distinct bipolar staining which is motile by means of 1–3 polar flagella. The organism is largely a xylem invader but is not limited to the xylem.

No immunity to the disease is known. Certain varieties possess a higher degree of resistance than do others particularly in certain localities. Green Mountain, Katahdin, and Sebago exhibit useful degrees of resistance. Cobbler, Chippewa, and Spaulding Rose have been reported susceptible.

COMMON SCAB

Common scab or corky scab of potato is incited by *Streptomyces scabies* (Thaxt.) Waksman and Henrici. This is a soil borne filamentous bacterium, which was first identified in 1890 in this country. The disease is distinct from powdery scab. The latter although superficially similar in appearance is limited to wet, cold soils. Common scab is one of the major potato diseases in many producing areas of the United States because of its influence on appearance, grade, and quality.

Symptoms of scab on potato tubers are modified extensively by inherent host resistance and to a lesser extent by environmental conditions. It is possible that strain variation of *S. scabies* may account at least to some extent for differences in scab type. Lesions range from russeting through deep pits. One system of describing lesion type is widely used in evaluating resistance in potato varieties in this country (Akeley *et al.* 1957). Type 1 lesions are restricted in size and are very superficial. Type 2 lesions are larger than type 1 but still superficial. Lesions of types 1 and 2 do not extend below the tuber surface and the scab lesion usually consists of a well developed layer of cork-like tissue covering the underlying tuber tissue. Type 3 scab is characterized by large, thick and rough lesions. Lesions may extend below the tuber surface or be raised above the surface. Type 4 lesions are deep pits extending up to one-

fourth inch or more into the tuber flesh. Russet areas on normally white skinned varieties such as Cobbler may possibly be the result of superficial scab infection. The surface area involved in scab lesions is of importance in assessment of damage. Clark *et al.* (1938) have presented drawings for determining the percentage of tuber surface involved in scab lesions. Activity of insect larvae in lesions may increase depth and extend scabbed areas. Scab lesions become deeper as mature tubers are left in the field before digging. There is no evidence that lesions become more severe in storage. Rot of tubers is not associated with scab infection unless other organisms such as soft rot or late blight have gained entrance through scab lesions.

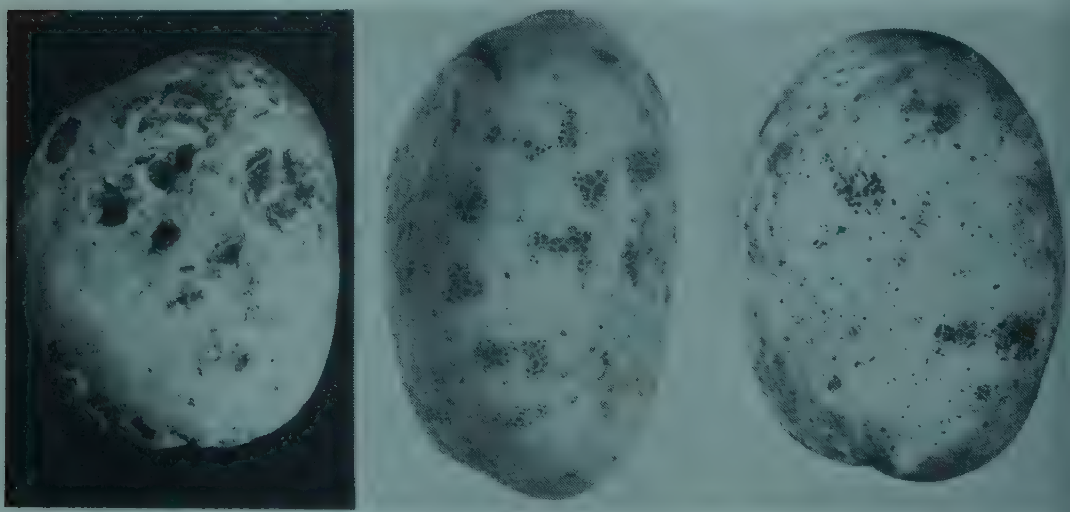

FIG. 28. COMMON SCAB ON TUBERS OF A SUSCEPTIBLE VARIETY (LEFT) AND RESISTANT VARIETIES (CENTER AND RIGHT)

S. scabies attacks all underground portions of potato plants, tubers, lower stems, stolons and roots. It produces scab-like lesions on fleshy roots of red beet, sugar beet, turnip, rutabaga, carrot, parsnip and is capable of attacking fibrous roots of a number of plants. On the tuber, *S. scabies* penetrates the surface in the area of greatest expansion, near the apex of the growing tuber and around the eyes. Infection occurs through stomata and lenticels in areas where the protective covering is either epidermis or newly formed cork (Fellows 1926). In scab resistant varieties the periderm of very small tubers persists as a living tissue throughout period of tuber development. In scab suspectible varieties, a mantle of collapsed defunct cells covers the periderm of the enlarging tuber (Cooper *et al.* 1954).

Streptomyces scabies (Thaxt.) Waksman and Henrici has been called *Actinomyces scabies* (Thaxt.) Gussow and *Oospora scabies* Thaxter.

Cultures of the organism are slow growing, often a gray with a bluish cast and with a velvety texture. Many isolates produce a dark discoloration of potato media. Hyphae are from .35 to 1.0 micron in diameter (Jones 1931). There is general agreement that hyphae are commonly within the cells of the host tissue. There is some evidence that the hyphae at first are intercellular (Lutman 1941). Strain variation in *S. scabies* is important (Schaal 1944). Although *S. scabies* is considered to be a single species, other species have been named on the basis of differences in morphology and type of lesion produced on potato tubers (Millard and Burr, 1926; Wollenweber 1920).

The streptomycete is typically soil borne surviving for considerable periods of time in the absence of potato. The preponderance of evidence is that long rotations involving crops other than beet is the best means of reducing soil populations (Goss and Afanasiev 1938; Hooker 1956). Scab has been reduced by planting soybeans as a cover crop between annual potato crops in California (Oswald and Lorenz 1956).

Scab develops in severity in relatively dry soils at high temperatures. Under field conditions these are not usually limiting factors as the disease is wide-spread over the United States. It is generally more severe in neutral or slightly alkaline soils than in acid soils (Blodgett and Howe, 1934). Sulfur and sulfuric acid soil treatments have been used for controlling scab through increase in soil acidity (Smith 1937; Hooker and Kent 1950). Soil treatments involving pentachloronitrobenzene although expensive, have given some measure of control (Hooker 1954).

Resistant varieties are the best means of avoiding losses due to scab. High resistance to scab is available in such varieties as Ontario, Menominee, Cayuga, Seneca, Cherokee, Russet Burbank and Russet Rural. Intermediate resistance such as that of Sebago is very useful in areas where scab is present but not a major problem in production. Susceptible varieties include Cobbler, Triumph, Katahdin, Chippewa, Pontiac, Kennebec, Saco and others.

LATE BLIGHT

Late blight of potato incited by *Phytophthora infestans* (Mont.) deBary is of major concern to potato growers and handlers because of its rapidly progressing rot of foliage and tubers in field and storage. When uncontrolled, the destruction of vines and tubers is spectacular. The Irish famine of 1845 to 1850 was due in great measure to loss of the potato crop by late blight. The disease was studied in detail in the British Isles by deBary in 1876 and by Ward in 1887. Jones *et al.* (1912) presented the first complete account of the disease in this hemisphere.

Symptoms on foliage usually appear from the time of blossoming

through harvest although they may appear earlier. Symptoms consist of rapidly expanding more or less circular lesions, brown when dry to almost black when moist. Lesions develop on all parts of the above ground portions of the plant. Under optimum conditions once infection has been established, vines are rapidly killed. When lesions are rapidly expanding, they are surrounded by a chlorotic green area one-eighth inch or more in width. A white sparse mold growth is present on lesions under good conditions for blight development. This consists of aerial hyphae on which sporangiospores are produced. There are no characteristic markings in the lesion as is the case with early blight.

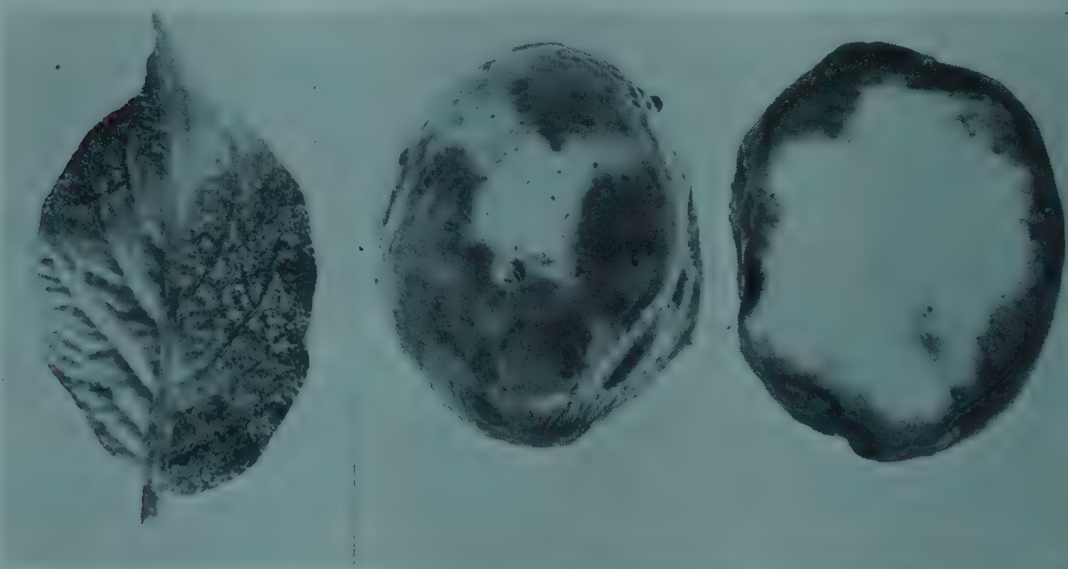

FIG. 29. LATE BLIGHT

Leaf showing sporulation of *Phytophthora infestans* (left). Tuber rot (center and right).

Tuber lesions are first reddish to purplish brown and somewhat irregular in shape. They are seldom sunken early in development but after some time in storage affected areas may become sunken with clearly defined margins. Lesions extend to irregular depths in a tuber but they are usually not over one-half inch deep. Internal tuber tissue at the margin of the lesion is flecked with small brown spots where necrotic areas extend to irregular depths into the healthy tissue. Under optimum conditions, the fungus may sporulate on the surface of the tuber producing tufts of mycelium especially abundant at the lenticels. Soft rot often follows late blight infection.

Within leaf and tuber tissue of susceptible varieties, the mycelium of *P. infestans* is situated between the cells sending haustoria into the cells (Jones *et al.* 1912). Haustoria may not be essential for nutrition of *P.*

infestans (Blackwell 1953). Aerial hyphae are produced on aerial portions of the plant and on tubers. These consist of characteristically branched hyphae on the tips of which ovate hyaline sporangia are successively produced. Sporangia average 21 × 33 to 17 × 24 microns depending upon environment during growth. Sporangia are produced over a range of 38° to 95°F. A relative humidity of 100 per cent is necessary for abundant sporulation. Spores are disseminated by splashing rain, water and wind. They lose viability rapidly in air at temperatures above 68°F. Sporangia germinate well between 42° and 75°F. either by germ tubes or by swarm spores. Spread of the fungus is most rapid through the host tissues at 68° to 74°F. Within fleshy tissue, the fungus survives at higher temperatures at least for short periods of time. The influence of environmental conditions on spore production, morphology, germination and infection has been studied by Crosier (1934). The fungus is able to survive relatively long periods of adverse field conditions in potato stem lesions (Clayson and Robertson 1956).

Spread of late blight and development of disease is precluded by adverse environmental conditions. Because of this, forecasting late blight incidence based on temperature and moisture relations has been attempted. In the northeastern United States one method of forecasting blight is based upon ten consecutive days with average seven day temperatures of 77°F. or less and a ten day total rainfall of approximately 1.2 inches (Hyre 1955).

Tuber infection during the growing season is accomplished by water borne inoculum. The importance of air borne inoculum in tuber infection at harvest has been emphasized by Bonde and Schultz (1945). Late blight tuber rot increases in severity in storage and transit, spreading from infected tubers to healthy tubers. Tubers should be *dry* and held at storage temperatures of 36°–40°F. to prevent losses.

P. infestans is carried over winter in infected tubers. Infected seed tubers usually rot before a plant is produced. Plants growing from infected cull tubers discarded in dump piles often provide an effective source of early season inoculum (Bonde and Schultz 1943). Furthermore, Webb and Bonde (1956) found a number of specialized races in populations of *P. infestans* from such heaps.

The relationship between resistance in potato and variability of *P. infestans* is described by Black (1952A and 1954). Resistance is of two distinct types. Field resistant plants are attacked by blight less severely than are completely susceptible plants. Field resistance, controlled by a series of minor genes, is a complex of morphological and physiological characters which limit the extent of disease development in susceptible varieties and the extent of necrosis in field immune forms. Resistance of

this type is present in Calrose, Sebago, Menominee, Ontario, Seneca, Sequoia and others (Peterson 1957). Hypersensitivity is lacking in field resistance (Black 1952A). A second type of resistance, field immunity derived from *Solanum demissum* is described as hypersensitivity in which cells are quickly killed, localizing the fungus (Black 1952A and 1954). This type of resistance is influenced by at least four different dominant genes. Each gene conditions hypersensitivity to the common race, O, and to at least one other specialized race of the pathogen. Varieties with this type of resistance (Peterson 1957) are Boone, Delus, Cherokee, Kennebec, Merrimack, Plymouth, Pungo, Empire, Placid and others.

Resistance to blight in the vines is not necessarily accompanied by resistance in the tuber (Bonde *et al.* 1940; Müller *et al.* 1939). In general, tuber resistance tends to follow foliage resistance but it is weaker and less consistent (Black 1952A). Tuber resistance depends on morphological and physiological differences between potato varieties (Bonde *et al.* 1940). Müller *et al.* (1939) presents evidence that the basis for the hypersensitive type of resistance in tubers and leaves may be the relative speed for production of a substance toxic to the fungus.

The fungus is variable, building up in virulence by passage through varieties intermediate in resistance (Reddick and Mills 1938). Isolates show adaptation to a particular variety of the host being more prolific and competing more effectively with other isolates of *P. infestans* on the more suitable variety (Black 1952B; Thurston and Eide 1953). Physiologic races of the pathogen may originate from oospores (Gallegly and Gallindo 1957). New physiologic races may arise within a population of a physiologic race (Black 1952B). The international system for designating the relationship of these four dominant genes for resistance and the several physiologic races of *P. infestans* has been adopted (Anon. 1954).

Control consists of elimination of cull piles to retard early season infection and inoculum build up. Fungicide protection of vines is necessary with copper, maneb, or zineb sprays applied regularly and frequently throughout the season. Thorough vine coverage is required. Prevention of tuber infection at harvest is avoided by delaying harvest until vines are matured, killing the vines with herbicides, or delaying harvest until vines are killed by frost. After killing vines, harvest should be delayed until infected tubers have begun to rot in the soil. Dry tubers should be stored in dry, well ventilated storages as close to 36° to 40°F. as possible.

EARLY BLIGHT

Early blight incited by *Alternaria solani* (E. and M.) Jones and Grout is an important production disease as it is present late in the season almost

every year wherever potatoes are grown. It attacks leaves, stems, and tubers, causing early maturity of the vines and yield reductions often approximating 50 bushels per acre.

On leaves and stems, early blight lesions are at first small, later expanding to more or less circular areas except where restricted by larger veins. Lesions are dark brown in color characterized by concentric zonation or target-like lines. Single lesions are seldom over one-fourth inch in diameter although lesions commonly coalesce. Characteristic spores of the fungus are present in the center of such lesions. In a sense, the disease is one of old age as it becomes severe after the blossom period when plants are tuberizing and approaching maturity. Leaf infection is one of the major factors in premature defoliation and reduction of yield at the close of the growing season.

FIG. 30. EARLY BLIGHT

Leaf showing angular lesion shape and concentric markings (left). Symptoms on stored tubers (center and right).

In the tuber, early blight is a disease of relatively minor importance. Lesions are at first somewhat circular in shape, firm and dark colored. They later become more irregular in shape with margins somewhat raised and disease tissue slightly sunken. Affected tissue is black to brownish black (gunmetal) in color, firm and leathery in texture. The margin between diseased and healthy tissue is clearly defined. Lesions expand slowly in storage and range in size from one-fourth inch in diameter to involve almost the whole tuber surface. Lesions become progressively deeper and may produce a somewhat shrivelled appearance of the tuber in relatively advanced infections. Lesions are at first rather shallow

approximately one-eighth to one-fourth inch deep but become deeper with age. Westphalen (1956) has described a second type of lesion which is considerably deeper than the type commonly encountered and may extend into the center of the tuber. This type of lesion is not commonly recognized in this hemisphere. Early blight lesions may serve as infection courts for other tuber rot pathogens.

Infection of tubers occurs at harvest time through either wounded or unwounded surfaces. Gratz and Bonde (1927) inoculated tubers by stirring infected vines around freshly harvested tubers from the time they were approximately one-half grown in August to October. They obtained lesions in 10 days although after 30 days lesions were larger in size and the disease on tubers was more severe. Bruising was an aid to infection but was not essential. Approximately twice the percentage of infection was obtained by bruising but the most typical lesions were obtained in the absence of bruises. Most typical lesions were obtained when dry leaves were brushed on dry tubers and the tubers kept dry for several days before being placed in storage. Klaus (1940) obtained infection in wounded and unwounded tissue. Infection of unwounded tubers occurred in epidemic proportions only on freshly dug tubers or on those with enlarged lenticels. The optimum temperature for tuber infection is 54° to 61°F. Very little disease developed at 41° to 45°F. and virtually none at 77°F. and above (Gratz and Bonde 1927). Westphalen (1956) observed little difference in spread between 41° to 59°F. and that spread of lesions was somewhat higher at 79°F. Six varieties were more severely infected at 79°F. while three others were more severely infected at 61°F. Storages should be held at 50°F. or lower to prevent spread of disease. Gratz and Bonde (1927) point out the problems associated with low temperature storage and subsequent lesion enlargement when tubers are warmed in transit.

Varietal differences in tuber susceptibility are marked. Among a limited number of varieties tested (Gratz and Bonde 1927), Spaulding Rose was very susceptible while Cobbler and Bliss Triumph were more resistant. Westphalen (1956) observed tuber resistance in two late German varieties.

Control consists of foliage spraying with zinc or manganese ethylene bis dithiocarbamate sprays to prevent foliage infection. Tuber injuries should be avoided at harvest and storage temperatures should be 50°F. or lower.

FUSARIUM TUBER ROTS AND FUSARIUM WILTS

For purposes of this discussion the Fusarium diseases of potato are grouped into three divisions. Because of the variability existing in this

genus of the fungi, the resulting poor definition of species, and because of the importance of environment on disease expression, there is considerable overlapping between these divisions. Certain Fusarium diseases of the potato are typically dry rots of the tuber in storage. Infection of tubers usually is through wounds developing in handling and harvesting operations. Other Fusarium diseases develop wilt in the field with characteristic symptoms of the vine and vascular discoloration of the newly formed tubers. Infection follows root or seed piece invasion. The third group of Fusarium diseases are intermediate between these two extremes with symptoms of vine wilting and of tuber rot.

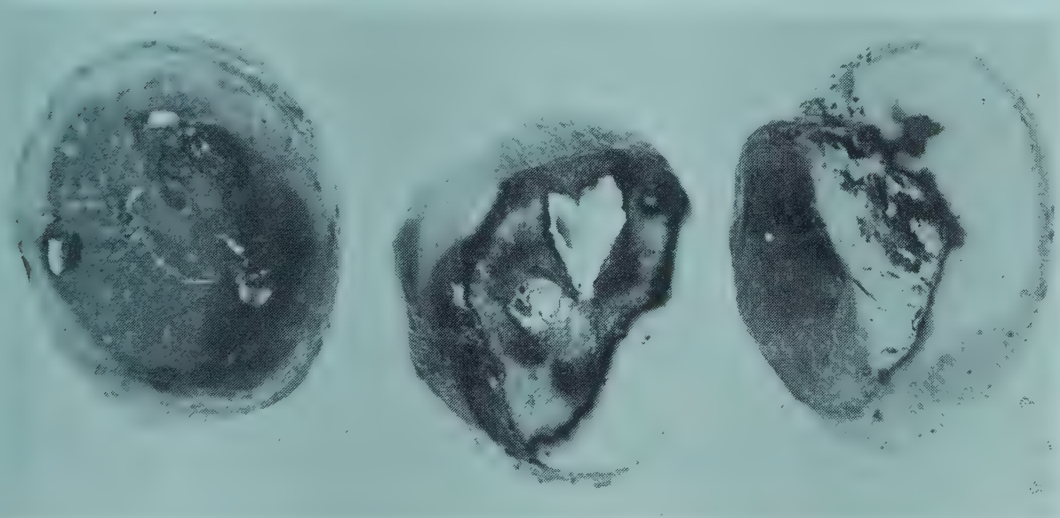

Fig. 31. Fusarium Tuber Rots Developing in Storage

Fusarium dry rot of tubers is one of the major problems in potato storage and handling as it is typically a soil borne disease entering the tuber through wounds. It is world wide in distribution. Rot is typically dry with affected tissue later becoming hard and chalky. In the early stages of infection, the rot may be quite moist or somewhat cheesy, and in some respects, similar to other soft, storage rots. Affected tissue later becomes hard and leathery with some tendency for circular shaped lesions on the surface of which compact mycelial tufts may be present. In cross section of tubers, the boundary between diseased and healthy tissue is clearly defined and cavities in rotted tissue are common. Carpenter (1915), has illustrated these rots well. Bacterial soft rot often is associated with infection by *Fusarium* spp. in which case the rot may be more nearly that typical of bacterial soft rot. Fusarium tuber rots of this type are not associated with vine symptoms. *Fusarium solani* f. *radicicola* and most of the *Fusarium roseum* group incite rots of this type. Certain isolates of

Fusarium avenaceum apparently are more typically wilt inciting fungi (McLean and Walker 1941).

Infection of tubers by the typical tuber rot Fusaria is through wounds associated with digging and handling operations. Less frequently, Fusarium dry rot follows infection by other tuber disorders such as late blight and frost injury. Since this is a wound parasite, considerable rot may develop in storage even though the crop did not evidence infection at harvest.

Immature tubers are highly susceptible to Fusarium rot. Tubers increase in resistance to infection at normal digging time. Early in the storage season tubers are most resistant but gradually they become increasingly susceptible as the storage season advances (Boyd 1952A; McKee 1954).

Varietal resistance to *Fusarium coeruleum* tuber rot has been studied by Boyd (1952B) using British varieties and by Ayers (1956) with *F. sambucinum* and *F. coeruleum* on North American varieties. Among the varieties tested Sebago, Keswick, Chippewa and Pontiac were very susceptible to rot incited by *F. sambucinum* f. 6 whereas Cherokee, Houma, Irish Cobbler, Warba, Merrimack and others were resistant. Keswick, Pontiac, and Warba were susceptible to *F. coeruleum* whereas Cherokee, Merrimack, Green Mountain, Ontario, Early Gem and Menominee were resistant.

F. solani f. *eumartii* incites a field wilt disease of the vines in which the tip leaves develop interveinal bronzing or chlorosis. Pith necrosis of the upper stem is common and the lower stem develops vascular discoloration and may in advanced stages be completely rotted. This is not the active type of Fusarium storage rot previously described. Infection of the growing plant is from infested soil usually through the roots although seed pieces may be infected. Stem end rot of newly formed tubers results from infection through the stolon. Vascular discoloration of the tuber may range from black to brown streaks (Goss 1936) to a light brown, watersoaked area up to one-fourth inch wide. Grading out infected tubers is almost impossible as the internal discoloration may be severe with little or no external evidence of disease.

Intermediate between the tuber rots and the wilt disease incited by *F. solani* f. *eumartii* are those associated with *F. solani* (Goss 1940), *F. oxysporum* (Goss 1936), and with certain types of *F. avenaceum* (McLean and Walker 1941). Vine symptoms of rosette, chlorosis, red to purple coloration, aerial tubers and rapid wilt follow rot of the lower stem. Root and seed piece infection from the soil is common. Members of this group usually are less pathogenic as wilts than *F. solani* f. *eumartii* (Goss 1936; McLean and Walker 1941). Rot of tubers may range from symp-

FIG. 32. FUSARIUM WILT
F. solani f. *eumartii.* Vascular discoloration (left and center) stem end rot of center tuber (right).

toms approximating those of *F. solani* f. *eumartii* to those more typical of the first described Fusarium tuber rots. Jelly end rot of freshly harvested tubers has been reported by Carpenter (1915). Fusaria commonly associated with potato tuber rots and wilts (classification of Snyder and Hansen) are listed below.

Fusarium roseum Link emend. Snyder and Hansen
  Syn. *F. avenaceum* (Fr.) Sacc.
  F. sambucinum Fkl. f. 6 Wr. and Rg.
  F. sulphurem Schl.
  F. trichothecioides Wr.
Fusarium oxysporum Schl. f. *tuberosi* (Wr.) Snyder and Hansen
  Syn. *F. oxysporum* Schl. f. 1 Wr.
Fusarium solani (Mart.) App. et Wr.
Fusarium solani f. *radicicola* (Wr.) Snyder and Hansen
  Syn. *F. coeruleum* (Lib.) Sacc.
  F. radicicola Wr.
Fusarium solani f. *eumartii* (Carp.) Snyder and Hansen
  Syn. *F. eumartii* Carp.

McKee (1954) contrasted penetration through tuber tissue by *F. coeruleum* and *F. avenaceum*. The former was more pathogenic than the latter. Hyphae of *F. coeruleum* grew through the intercellular spaces without causing a marked reaction in adjacent host cells. The hyphae of *F. avenaceum* killed and penetrated tuber cells more rapidly than *F. coeruleum*. Restriction of lesions in tuber tissue was associated with

suberin depositions on the host cell walls and in the intercellular spaces. Weiss *et al.* (1928) report that suberin formation was incapable of preventing infection in their trials but that periderm formation was effective. In the Rural New Yorker 3 or 4 days at 70°F., 5 or 6 days at 60°F., and 8 days at 50°F. or lower were required for periderm formation. Varietal differences in speed of wound periderm formation were observed.

High storage temperatures favor development of Fusarium rots. Certain species of tuber rot Fusaria may be inhibited at 50°F. while others may continue to cause rot at temperatures approaching the lowest safe temperatures for potato storage. High relative humidity is more favorable to rot than low relative humidity (Goss 1921). Differences in relative humidity were negligible over a range of 70 to 95 per cent (Weiss *et al.* 1928). The presence of moisture in wounds, and its persistence until infection has occurred, probably is of greater importance in influencing infection than relative humidity alone. Direct effects of temperature and relative humidity on the pathogen are of less importance in influencing infection than are the influence of these factors in wound healing of the tuber.

Avoidance of mechanical injury to tubers is the greatest single factor in prevention of Fusarium dry rot. It is accomplished by careful handling during all operations. Control consists of removal of superficial moisture from the tubers as promptly as possible but maintaining a sufficiently high relative humidity and temperature to permit wound healing. Outside of careful grading there is little that can be done to improve lots of tubers showing appreciable vascular discoloration and stem end browning. Severe incidence represents a considerable loss to the producer.

VERTICILLIUM WILT

Wilt incited by *Verticillium albo-atrum* Reinke and Berthold is of greatest importance in the potato growing areas of Canada and the northern portions of the United States. Importance of the disease has been emphasized in recent years by increased length of the growing season resulting from improved cultural practices. The disease causes premature death of the plant resulting in reduced yield. Internal discoloration of tubers impairs market quality severely. The disease was described in considerable detail by Pethybridge (1916).

Symptoms increasing in intensity from blossom time to harvest consist of a wilting and general yellowing or chlorosis progressing from the base of the plant upward. Before death of the stem, lower leaves wilt and die remaining attached to the stem with a terminal tuft of chlorotic leaves remaining at the tip. Reddish brown vascular discoloration may

extend from the base some distance up the stem. Symptoms may begin unilaterally on a stem or involve only a few stems of the plant.

Tubers from infected plants often develop reddish to light brown vascular ring discoloration which in severe cases may extend throughout the length of the tuber. Eyes are often pink in color. Folsom (1953) has described occasional reddish brown cavities in the tuber. The brown eye symptom described in detail by Robinson *et al.* (1957) occurs in association with Verticillium wilt infection. A fluorescent species of Pseudomonas is present in such affected tissue.

Fig. 33. Verticillium Wilt Symptoms in Tubers

Reddish-brown internal vascular discoloration near the stem end (left). Discoloration of eyes at the apical end. External appearance (center) and internal tissue discoloration of same tuber (right).

Verticillium wilt infected tubers with 97 per cent vascular discoloration were not predisposed to rot nor was severity of vascular discoloration increased during a seven month storage period at 40°F. Pink eye tubers should not be stored as there is some tendency for breakdown in storage (Friedman and Folsom 1953). Vascular discoloration of the tuber can not be considered diagnostic of Verticillium wilt infection (McKay 1926). *V. albo-atrum* may be isolated from healthy appearing tubers (Muncie 1954).

The fungus has a wide host range and survives in the soil infecting potato plants through the roots. Robinson *et al.* (1957) isolated Verticillium from healthy appearing Cobbler stems up to twelve inches above the soil line and observed that the fungus advanced through stolons into tubers without the development of wilt symptoms. Resistant varieties were also symptomless carriers.

The importance of surface borne inoculum on seed tubers has been

demonstrated by seed treatment trials (Robinson and Ayers 1953; Robinson *et al.* 1957). Crop rotation between susceptible crops is important in reducing disease severity providing that inoculum borne on the seed tuber surface is removed. There is some evidence that relatively short rotation between potatoes may be effective (Robinson *et al.* 1957). Folsom (1957) found four years between crops sufficient to reduce Verticillium wilt.

Resistance in potato varieties varies to some extent in different localities. A rather large number of varieties have been classified for resistance (McLean and Akeley 1957).

VIRUS DISEASES

Virus diseases generally cause disorders of the plant evident in the foliage as reduced vigor, abnormal color, or malformation. These diseases usually are of minor importance other than reducing yield except when they interfere with the quality of the stored crop.

Photo by J. H. Muncie

Fig. 34. Virus Leaf Roll

The healthy center plant is surrounded by leaf roll infected plants in different stages of leaf roll severity (right and center). Net necrosis from current season leaf roll infection (right).

Leaf roll is characterized by an upward rolling and brittleness or leathery texture of the leaves, rigidity of the plant, and in advanced cases dwarfing and abnormal leaf coloration. Tubers of plants in early stages of infection develop necrosis of the phloem called net necrosis (Schultz and Folsom 1921). In Maine, leaf roll net necrosis develops mostly during the first 2 or 3 months' storage. Incidence is highest at 45 to

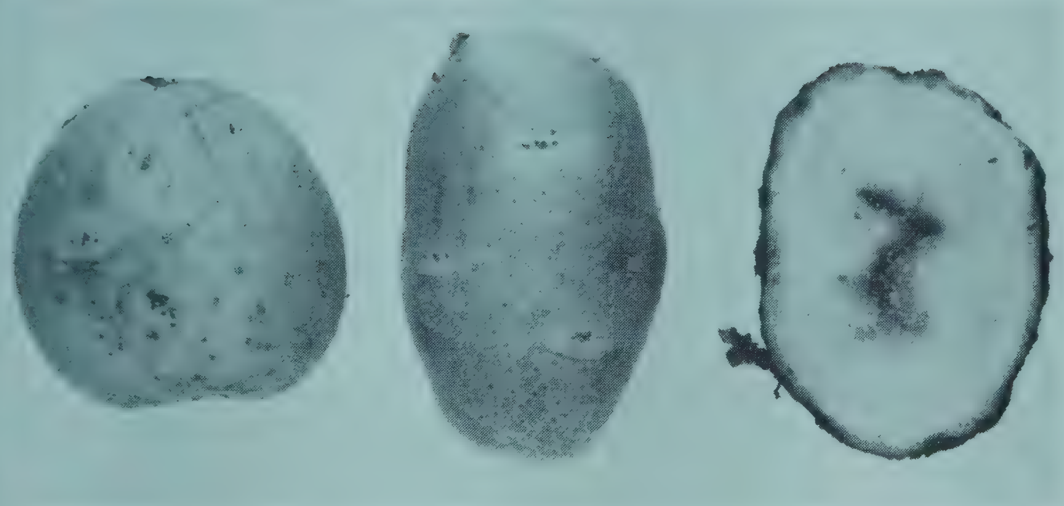

Photo by J. H. Muncie

FIG. 35. SPINDLE TUBER (CENTER) AND HEALTHY TUBER OF SAME VARIETY (LEFT), YELLOW DWARF NECROSIS IN TUBER (RIGHT)

50° F. and is low at 33° and at 70° F. Threshold temperatures during the first 60 days of storage are capable of changing potential net necrosis tubers so that net necrosis does not develop (Folsom 1946A). Davidson and Sanford (1955) studied net necrosis in tubers and observed that phloem necrosis was highest when plants were inoculated with leaf roll during the period of rapid tuber expansion. Incidence of phloem necrosis of tubers was low following early season inoculation.

Varieties with high resistance to net necrosis in the tuber are Bliss Triumph, Calrose, Chippewa, Essex, Katahdin, Kennebec, Mesaba, Placid and White Rose. Varieties evidencing virus leaf roll net necrosis are Ashworth, Cayuga, Chenango, Green Mountain, Irish Cobbler, Mohawk, Ontario, Red Warba, Russet Burbank, Snowdrift and Warba (Folsom 1952).

Spindle tuber and unmottled curly dwarf are related diseases. Tuber symptoms of both diseases are similar except that symptoms of unmottled curly dwarf are somewhat more pronounced. When compared to healthy tubers, eyes on diseased tubers are increased in number and become more shallow, skin is more tender and flesh is more brittle. Diseased tubers assume a cylindrical shape and color in varieties such as Bliss Triumph is less intense. Reduction in size and number of tubers is more pronounced with unmottled curly dwarf than with spindle tuber. Bumpiness of tubers, necrosis around lenticels and internal net necrosis occur occasionally with the latter disease (Goss 1930; Folsom 1946B).

Yellow dwarf symptoms of the vine consist of rosetting, shortening of the internodes, dwarfing, leaves rolled and curled. Foliage color may be

dark green in the early stages to yellow in more advanced stages. Pith necrosis is present in the stem. Tubers evidence necrosis in the interior or outside the vascular ring. Tubers are often small, malformed and have numerous growth cracks (Barrus and Chupp 1922; Muncie 1935; Walker and Larson 1939). Russet Burbank, Warba and Sebago varieties have a high degree of resistance under field conditions (Larson 1945).

Calico is a bright yellow mosaic of the leaflets associated with infection by strains of alfalfa mosaic. Oswald (1950) observed a strain causing necrosis of the vines and severe necrosis of the tubers. Necrosis develops first near the stolon and in the cortical tissues under the skin. Occasionally the symptoms become more severe in storage. Slagg (1952) reported shortening of tubers, cracking, malformation and corking of the bud end of the tuber.

Corky ringspot has been reported from Florida and the state of Washington but undoubtedly occurs elsewhere in the United States. It is generally of minor importance. Symptoms consist of brown concentric rings or portions of rings on the surface of tubers. Skin may be cracked or evidence shallow irregularly shaped corky depressions. The same ring-like symptom may be present in the internal flesh of the tuber and brown corky areas may be scattered through the flesh (Eddins *et al.* 1946). This virus apparently is related to the soil borne, potato stem mottle virus present in Europe (Walkinshaw and Larson 1958).

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R. L. Sawyer

Sprout Inhibition

Chemical inhibitors have been available for commercial application since about 1947. From the time Elmer (1932) discovered that a gas given off by apples would reduce sprouting of potatoes, chemical inhibitors have held an interesting potential. Major emphasis on chemical inhibitors in research programs did not take place until about 1945. Since that time they have been a part of the research programs of most of the major potato areas of the world.

The increased interest in chemical inhibitors can be traced to several factors. (1) During World War II, a need was seen for some means other than refrigeration which could keep produce sprout-free while in transit to all parts of the world. Consequently, the Quartermaster Corps has had much interest in chemical sprout inhibition and has underwritten a considerable amount of research in this field. (2) Potato processing industries using deep fat frying are taking a larger portion of total potato production each year. For curing and color control reasons, these processors would like to have their product stored at 50°F. or higher. This puts a serious limitation on the use of temperature alone for the control of sprouting. (3) Potato processors who know they are going to require a given volume of potatoes would like to be able to purchase as large a portion of the raw product as possible at periods of peak supply when prices tend to be low. In order to keep these potatoes relatively sprout-free for the maximum time desired, some method other than temperature manipulation has to be used. (4) Intermediate crop areas such as Long Island which store a larger part of their crop each year, frequently encounter sprouting problems early in the storage season. Sprout controlling temperatures cannot be obtained in storage until after the crop has been harvested for several weeks. Frequently the crop at harvest has little, if any, rest period left.

Manipulation of storage temperature has been the main method used to control sprouting. Chemical inhibitors in the form of dusts applied as tubers go into storage and a spray which can be applied to potato foliage have found commercial acceptance. Chemical inhibitors have been applied in waxes and in the washing water to keep potatoes from

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sprouting in market channels. The sprout inhibition field has developed rapidly and materials that demonstrate very strong suppression are in research programs. Because of this rapid development and because of the possible changes in federal rules concerning the use of new materials, or materials previously accepted, up to date federal regulations should be consulted before using any of the new inhibitors or those discussed here.

CONSIDERATIONS IN A SPROUT CONTROL PROGRAM

Chemical inhibitors are only part of the picture in a good sprout control program. Temperature manipulation is undoubtedly the most important factor. Varieties differ in length of rest period. Merrimack for example, will remain sprout-free in storage as much as several weeks longer than Katahdin. In some areas planting and harvest dates will affect the maturity and rest period of the crop at harvest and therefore should be included in a sprout inhibition program. Processors who wish to hold produce sprout-free and in the best possible condition for periods up to a year will have to utilize all of the factors which affect sprouting.

The first consideration in any sprout inhibition program is temperature control. Temperature not only affects sprouting but also influences storage rots, respiration and moisture loss. Sprout growth is very slow at temperatures of 38° to 40°F. even when tubers are out of their rest period. As the holding temperature is raised above 40°F., the rate of sprouting, respiration, moisture loss, and development of storage rots increases. Above 50°F. the increase is more rapid than between 40° and 50°F. Sprouting and respiration may be decreased by the use of chemical inhibitors, but if the temperature is not controlled serious storage losses may result from the effect of moisture loss and storage rots.

Processors dealing with fried products frequently have color control problems when potato storage temperatures are lower than 50°F. Some varieties will not recondition from storage temperatures under 50°F. Varieties that do recondition require a longer curing period if the temperatures have been below 50°F. To get the best quality and longest storage life, the temperature should be held as low as possible taking into consideration color control. Chemical inhibitors should be used as accessories to temperature manipulation.

CHEMICAL INHIBITORS

Several chemical inhibitors have been accepted commercially in the United States. There are inhibitors which have promising aspects and have been in research programs for several years although they do not have federal clearance or commercial acceptance in the United States

as yet. The commercially accepted inhibitors, and those which have appeared most promising in research programs, are discussed in the following paragraphs.

Tetrachloronitrobenzene (TCNB)

Tetrachloronitrobenzene has found some commercial acceptance in several European countries, Australia and the United States. In the United States its principal region of acceptance has been Long Island, an intermediate potato crop area, which frequently encounters sprouting in storage. It has been used in Maine by potato processors. This material is marketed in the United States under the trade name of Fusarex.

The sprout inhibiting properties of TCNB were first noticed when it was used for fungicidal purposes. Emilsson *et al.* (1949) have reported that TCNB has a beneficial effect on some of the storage rot organisms. Cunningham (1953) produced good evidence indicating that TCNB will delay and inhibit wound cork formation and not prevent infection and growth of Fusarium dry rot. There are several reports which indicate that TCNB is a relatively weak inhibitor. Ellison (1952) reported considerable sprouting around the edges of treated bins. Poor results have been obtained when there has been free ventilation of air from the storage. Sawyer (1955) found that the use of some ventilation with TCNB was desirable in order to control the storage temperature. Tubers removed from the vapors of TCNB for several weeks have lost all traces of inhibition and produced a normal crop when used as seed Brown and Reavill (1954).

Commercial Application.—TCNB is available in the United States as a six per cent dust and is used at a dosage of one pound per ten bushels of tubers. Dosages less than this do not give dependable sprout inhibition. The usual method of application is through a small fertilizer applicator placed over the storage elevator and geared to the elevator. This material can be used in conjunction with forced air ventilation systems; however, ventilation should be kept to the minimum necessary to bring the temperatures down as close to 40°F. as possible, or to the lowest temperature that can be attained without detrimentally affecting

TABLE 13

RELATIVE SPROUT INHIBITION BY MENA AND TCNB APPLIED AS DUSTS TO GREEN MOUNTAIN POTATOES[1]

Inhibitors	Gm. Sprouts per 100 tubers
MENA (1 gm. per bu.)	37
TCNB (2.7 gm. per bu.)	85
Check	242

[1] From Ellison and Cunningham (1953).

curing and color control. Table 13 indicates the ability of TCNB to control sprouting.

The main disadvantage with this material is the relatively weak inhibition obtained at a cost of approximately five cents per bushel. The dust occasionally has caused discoloration problems on table stock tubers even though its color has been made to blend with the skin of the potato as much as possible. This would not affect tubers for processing or table stock tubers washed after storage and before marketing.

Maleic Hydrazide (MH)

Of the chemical inhibitors, maleic hydrazide has been tested more and received a wider range of acceptance than any other commercial inhibitor in the United States. Greatest use of this chemical has been with potato processors who plan to hold potatoes long enough to require the use of an inhibitor.

The importance of time of application was demonstrated by Kennedy and Smith (1951 and 1953). Sprays applied early in the season caused increased tuber set and yield reduction. Applying the material before vines were in an advanced stage of maturity so that the material would be translocated was of major importance in obtaining sprout control. Kennedy and Smith (1951 and 1953), Wittwer and Paterson (1951), Highlands *et al.* (1952), Franklin and Thompson (1953) all found that satisfactory sprout control could be obtained from maleic hydrazide sprays applied several weeks before harvest. Denisen (1953) found that a blossom fall application of maleic hydrazide gave less detrimental effects to the tubers than earlier sprays. Sawyer and Dallyn (1958) found a blossom fall application most satisfactory. Salunkhe and Wittwer (1952) obtained beneficial effects on specific gravity and color of potato chips from the use of maleic hydrazide but in general other workers have not obtained these effects.

Commercial Application.—Maleic hydrazide is applied as a spray to potato foliage in the regular insecticide and fungicide sprayer. Although it is compatible with most insecticides and fungicides care should be taken that it mixes with the particular materials being used. Timing of the spray is very important as indicated in Table 14. Plants must be actively growing in order that sufficient material be translocated from the foliage to the tuber. In the most northern growing areas, application of three pounds per acre 4 to 6 weeks from harvest gives good sprout control. In areas where there is considerable leeway in planting and harvesting dates, a blossom fall application gives good sprout inhibition. Tubers should be well past the setting stage. Too early an application causes a heavy set with few tubers reaching marketable size and shape.

TABLE 14

EFFECT OF TIME OF APPLICATION OF MALEIC HYDRAZIDE SPRAYS ON YIELD AND SPROUTING OF KATAHDIN TUBERS[1]

Spray Time	Yield		Sprouting	
	1954	1955	1954	1955
	Bushels per Acre		Gm. Sprouts per Kg. Tubers	
Early bloom	580	245	0.66	1.98
Full bloom	560	422	0.16	0.17
Blossom fall	573	561	0.69	0.33
2 weeks after blossom fall	586	570	1.25	1.59
4 weeks after blossom fall	595	566	4.00	4.84
Check	596	568	5.50	14.29

[1] From Sawyer and Dallyn (1958).

One of the main disadvantages of this material is the time of application. Since the only method of application is a foliage spray, growers have to apply the material long before there is any actual need for a sprout inhibitor. A processor would need to have his potatoes contracted by the middle of the growing season and the use of MH specified to insure a supply of treated tubers for storage. The cost of MH depends entirely on yield per acre, however, it will average about five cents a bushel. This is expensive in comparison with the potential cost of some of the new materials such as CIPC or MENA by volatilized gas application.

Methyl-Ester of Alpha Naphthalene Acetic Acid (MENA)

MENA was the first chemical inhibitor used commercially to any extensive degree in the United States. Approximately 500,000 bushels were dust-treated on Long Island as early as 1947 (Smith and Scudder 1947). It has been tested commercially in several foreign countries.

The early success of this material applied as a dust to potatoes going into storage was short-lived. Serious storage losses were encountered which were explained by the work of Ellison and Cunningham (1953) and Cunningham (1953). MENA inhibited the formation of wound periderm and thus permitted the entrance of Fusarium dry rot organisms. Many methods have been used to apply MENA. Denny (1945), Smith (1946), Marth and Schultz (1950) and Luckwill (1947) used impregnated paper and dusts with satisfactory results. Ellison and Smith (1948) obtained some inhibition by field sprays. Findlen (1955) showed that MENA could control sprouting in market channels by application in the washing water or wax emulsions. Sawyer and Dallyn (1957) found that in storages with forced air ventilation the material could be vaporized by hot plate in the storage ducts with effective inhibition.

Commercial Application.—MENA is available as a dust or a liquid to be applied as potatoes are going into storage. Long Island growers

stopped using this material entirely after serious storage losses in the late 1940's, due to its effect on wound periderm formation. If MENA is to be used on tubers as they are placed in storage, care should be taken that potatoes have well set skins and that there is a minimum of bruising. An application of one gram per bushel of tubers gives stronger sprout suppression than does TCNB. It is essential that distribution be uniform from the standpoint of control of sprouting and influence on wound periderm formation. Care should be taken not to ventilate more than is necessary to obtain the temperatures desired in storage.

The gas application of MENA to forced air ventilated storages of the proportioning air type gives effective inhibition at one gram per bushel and does not have any effect on wound periderm formation, when applied after a normal healing period. The material is vaporized in the ducts on a hot plate at a temperature of 392°F. The storage ventilation equipment is set for recirculation only during the time of application and for 24 to 48 hours after application. After this time the storage ventilation equipment is once more set for the use of cold outside air to keep storage temperatures at the level desired.

To control sprouting in market channels MENA has been used in a wax emulsion or a water solution during the washing operation as tubers are removed from storage. A dosage of one-half gram per bushel of tubers gives effective sprout control to non-dormant tubers for about four weeks depending somewhat on the temperatures in the marketing operation.

Isopropyl-N-Chlorophenyl Carbamate (CIPC)

CIPC and a closely related compound, isopropyl-n-phenyl carbamate, (IPPC) have not had federal clearance in the United States. They have been used in Australia and Europe. CIPC is the strongest chemical yet found in the sprout inhibition field. Inhibition tends to be complete with no sprouts developing under ideal application conditions.

Marth and Schultz (1950) found CIPC controlled sprouting for four months at a temperature of 70°F. when applied as a dust. A water dip was also very effective. Rhodes *et al.* (1950) found that IPPC was more effective than MENA. CIPC has not been effective as a field spray (Marth and Schultz 1950). Sawyer and Dallyn (1957) applied CIPC as a gas to stored potatoes at one-fourth gram per bushel and obtained good sprout inhibition. Hendel (1957) found that air distribution is very important for accurate distribution of CIPC applied as a gas. Cetas and Sawyer (1956–1957) and Hendel (1957) have found that CIPC inhibits wound periderm formation similar to MENA. No adverse effects on processing quality have been encountered.

Since CIPC has a serious inhibiting effect on wound periderm formation the same care must be taken on treatment of tubers going into storage that is taken with MENA. Tubers should have well set skins and a minimum of bruising. Distribution of the material should be uniform for the control of sprouting and to minimize the effect on wound periderm formation. The material should not be used at any greater concentration than the minimum necessary for sprout inhibition. A dosage of one-half to three-fourths gram per bushel of tubers gives good sprout control as a dust or spray.

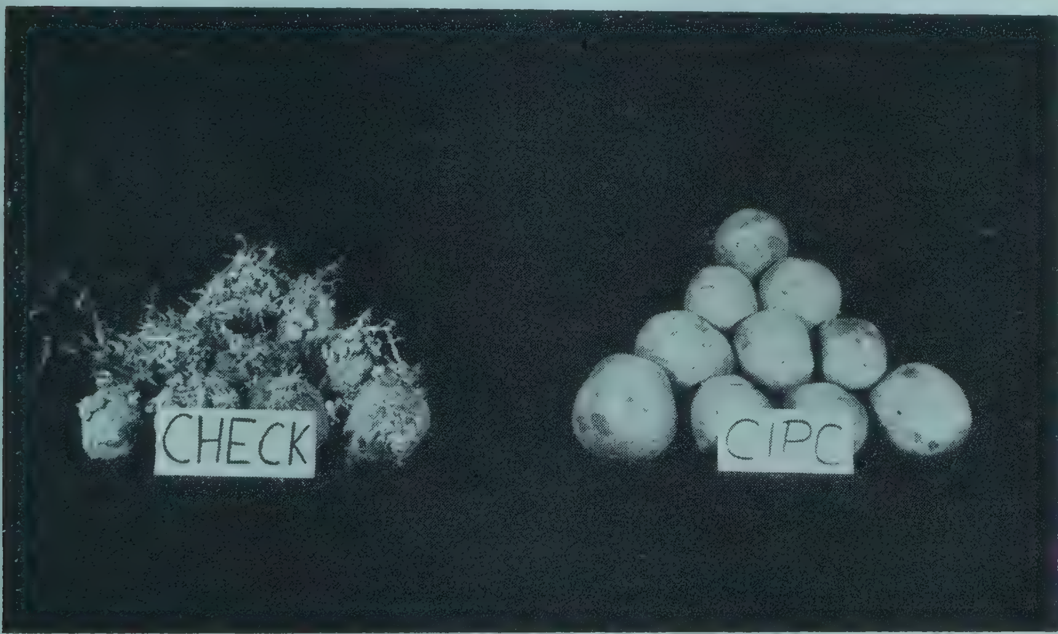

Fig. 36. Typical Sprouting of Check Tubers and Tubers Treated with One-Half Gram of Vaporized CIPC Per Bushel at the End of the Rest Period and Then Held 9 Months at 50°F.

When CIPC is used as a gas in storage, application can be delayed until after wound periderm formation has taken place. A dosage of one-fourth gram per bushel of tubers gives good sprout inhibition by this method. The storage ventilation equipment is set for recirculation only and CIPC is vaporized in the fan housing compartment or duct system by heating to a temperature of 392°F. The storage fans are left on recirculation for a period of 24 to 48 hours after the material is volatilized and then the ventilation equipment is once more set for use of cold outside air to keep storage temperatures at the desired level. Fig. 36 indicates strong sprout inhibition obtained with CIPC from vaporized application in storage.

FIG. 37. IRRADIATED KATAHDIN TUBERS

At left, gamma irradiated with 20,000 REP; at right, fast electron irradiated with 20,000 REP; center check. Tubers held for 12 months at 40°F.

Irradiation

Irradiation is a very potent sprout inhibitor and has had considerable publicity. It has not received federal clearance for use in the United States. Sparrow and Christenson (1954) observed that certain irradiation dosages gave excellent sprout control for as long as 15 months at 40°F. Brownell *et al.* (1956) found irradiation from 15,000 to 200,000 REP inhibited periderm formation completely. Sawyer (1956) found that irradiation increased the incidence of black spot, after cooking darkening, and storage rot. Chipping color was not affected.

Commercial control of sprouting can be attained with most varieties between 5,000 and 10,000 REP. At these dosages the effect on the various darkening reactions and storage rots associated with the potato tuber are minimized. In order to use the potent sprout inhibiting qualities of irradiation it is essential to use the minimum dosages necessary for sprout control to avoid detrimental effects on the darkening reactions and storage rots. Care in handling to avoid bruising is also essential because of the effect of irradiation on wound periderm formation. Fig. 37 indicates the sprout control obtained from irradiation, also the effect on storage rots when dosages more than necessary for sprout inhibition are used.

Alcohols

Several of the alcohols give good sprout inhibition with potatoes. Vapors of amyl or nonyl alcohols have been used on a small scale commercially in England. These materials have had no federal clearance for use in the United States.

Most of the work with alcohols has been done by Burton (1956) who found that sprouting of potatoes could be controlled with a concentration of about 1 mg. per liter of air with amyl or nonyl alcohol. Ventilation for a two-week period with the alcohol vapors was alternated with a two-week period without the vapors for as long as sprout inhibition was desired. Burton (1958) indicated that the rate of ventilation should be from 3.5 to 5.3 cu. ft. of air per minute per 2200 lbs. of tubers. Alcohol concentration in the air can be obtained by determining the rate of air flow and adjusting the drip of alcohol on a small hot plate at the fan intake. Sawyer (1957) has obtained sprout inhibition with several alcohols and observed lenticel pitting whenever the concentration in storage became too high.

GENERAL DISCUSSION

Chemical inhibitors are available for application in several ways. Maleic hydrazide has to be applied as a field spray. MENA, CIPC and TCNB can be applied as dusts or sprays to potatoes going into storage. MENA, CIPC and the alcohols can be applied as gases to potatoes after they are in storage. Irradiation has to be applied before tubers go into storage.

Maleic hydrazide must be applied during the growing season. This is too early for many growers to be thinking about sprout inhibition since an adequate determination of the storage program has not been made at that time for a given year.

MENA, CIPC and TCNB inhibit wound periderm formation. Thus, there is always the possibility of encountering rot problems in storage when these materials are applied as dusts or sprays to freshly harvested potatoes. The influence on wound periderm formation appears to correspond to the strength of sprout inhibition. TCNB, a relatively weak inhibitor when compared to MENA or CIPC, affects wound periderm formation much less than MENA or CIPC. Irradiation, a very potent inhibitor, has a strong effect on wound periderm formation at dosages which completely eliminate sprouting. With most of the chemical inhibitors, apparently, the mechanism that prevents cell division for sprouting also prevents cell division for healing.

The gas application of inhibitors such as MENA, CIPC and the alcohols has several advantages over the other methods of sprout control. The application can be delayed until a definite need is seen for sprout control. Table 15 indicates the sprout inhibition obtained with CIPC and MENA applied as vapors after tubers are in storage. The effects will be longer lasting with the delayed application in storage than from an application of the same material at harvest. The gas application can be de-

TABLE 15

EFFECT OF CIPC AND MENA ON SPROUT PRODUCTION WHEN APPLIED AS VAPORS TO KATAHDIN TUBERS AT THE END OF THE NORMAL REST PERIOD[1]

Dosage, Gm. per Bushel		Gm. Sprouts per Kg. Tubers	
		44 Days at 70 °F.	84 Days at 50 °F.
CIPC	1	0	0
	1/2	0	0
	1/4	1	0
MENA	1	3	2
	1/2	3	1
	1/4	5	13
Check		18	57

[1] Sawyer and Dallyn (1957).

layed until after wound periderm formation has taken place on harvesting and storing bruises. All of the methods of sprout control which require an application before a need is seen are wasted during years when the rest period and cool storage temperatures are sufficient to keep tubers in good condition for the normal storage period. Applications of MENA and CIPC in storage are made only once whereas applications with the alcohols are necessary about every two weeks once sprouting has been noticed.

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Ora Smith

Effect of Transit and Storage Conditions on Potatoes

TRANSPORTATION OF POTATOES

During transit potatoes for processing, particularly for chips, should be kept at temperatures between 50° and 75°F. This applies to the early crop grown in the south and southwest as well as to the late crop grown in the north. It also includes potatoes in transit from field to storage, from storage to processing plant and also before and after reconditioning. If potatoes are held several days at 40°F. or below, reducing sugars accumulate resulting in dark color of processed product. Temperatures above 75°F. for very long periods of time may increase certain types of storage rot diseases and, in fairly air-tight areas, may result in black-heart, a discolored breakdown of the tissues in or near the center of the tuber. Ventilation in railroad cars and trucks during transit is considered highly desirable.

Many processors desire potatoes which have already been reconditioned and are ready for processing on arrival at the plant. Sometimes potatoes process to a desirable color before shipment but, due to low temperatures in transit, they are undesirable on arrival at the plant.

Truck Shipment

When potatoes for processing are transported, especially during periods of low temperatures, it is well to have floor insulation to prevent low temperature damage to the bottom layer of potatoes. An alternative is to have a raised slatted floor several inches above the permanent floor to provide an area for ventilation or air movement below the potatoes and to prevent direct contact of potatoes with a cold floor. Side and end walls and ceiling also should be insulated to avoid frost penetration and low temperature injury of potatoes. Glass fiber insulation is often used in trailers. Trailers may be preheated with a "hot blast" or other type of heater before loading. For maintaining proper transit temperature one or more liquefied petroleum gas heaters can be placed in various portions of the trailer. Charcoal burners also are used to some extent. Some heaters are equipped with a thermostat while others are manually controlled. Regardless of the type of insulation, floor protection or type of heater, it is well to have considerable air circulation within the truck to avoid cold or hot areas. In a number of experimental shipments Findlen

and Hansen (1958) found that one or two heaters of 10,000 to 28,000 B.t.u. output per hour in each truck load of potatoes maintained inside temperatures between 45° and 74°F. with outside temperatures from 50° above to 16°F. below zero. With poor air circulation, temperature of potatoes in the top center of some loads increased to almost 90°F., in some instances 30° higher than temperatures near the floor in the same load.

The problems encountered during truck shipment of early harvested spring and summer crop potatoes are somewhat different. The main difficulty here is to prevent excessive temperature rises and to prevent sunscald and drying of potatoes transported in open trucks. A large portion of the Sebago and Russet Sebago potatoes produced in Alabama and Florida are transported to northern areas for chip processing. Many of these potatoes are shipped by truck for long distances. Potatoes shipped in May by semi-open trucks with tarpaulin cover from Alabama to Wisconsin did not carry or store as well as comparable potatoes shipped in closed vans (Kushman 1958). This probably is due to excessive loss of moisture from the most exposed positions in the truck which caused damage by desiccation and promoted decay. Potato temperatures rarely went below 50°F. during transit and chip color was not affected by method of shipment. Potatoes immediately following transit and in subsequent storage at 70°F. produced chips darker than those at harvest but color was always at a satisfactory level.

Rail Shipment

Potatoes are shipped largely in standard end-bunker refrigerator cars equipped with air circulating fans under the floor racks. In studies of winter shipment of potatoes from the Red River Valley of North Dakota and Minnesota to Wisconsin and Texas, Findlen and Hansen (1958) used the protective service provided by 2 to 4 alcohol heaters with thermostats set at 60°F. Under these conditions, with potatoes at about 70°F. when loaded, the temperature fell about 10 degrees for 48 hours when outside temperatures were low. As outside temperatures rose to 30°–40°F., the potato temperature gradually returned to 64°–68°F. However, when potatoes at 40°F. were loaded, desired temperatures were not reached until the third or fourth day in transit. The temperature in the bottom layer lagged behind that in the top of the car.

Losses from shrinkage and decay of Alabama grown Russet Sebago potatoes shipped to Wisconsin in May were greater under standard ventilation service by rail than for those shipped in ventilated vans (Kushman 1958). This probably was a result of the longer transit period by rail. Losses during subsequent storage, however, were less for potatoes shipped

by rail than by van and at the end of the storage period losses were equal from the two methods. Potatoes shipped by van and by rail produced chips of similar color.

Shipping Containers

Until recently practically all shipments of potatoes for processing were made in 100-lb. burlap bags. Within the last few years a large number of processors have become interested in storing potatoes in large pallet boxes with capacities of 1000 to 2200 lbs. of potatoes. If potatoes to be stored in this manner are shipped in 100-lb. bags it requires considerable hand work and time to empty the potatoes from bags into the boxes. Bruising also is entailed during this process. Hence, a few studies have been made as to the feasibility of transporting potatoes in pallet boxes from the field or farmers' storage to the processing plant.

Since pallet boxes of potatoes are lifted and transported with power lift trucks, their filled weight up to a maximum of about 2200 lbs. is not unwieldy. The limiting dimension in commercial carriers is the inside width of trailers or rail cars and the width of doors. A box approximately $3^1/_2$ feet $\times$ $3^1/_2$ feet $\times$ 4 feet will meet these requirements and will hold 1900 to 2000 lbs. of potatoes. Some boxes are nailed and of permanent construction, others are of knock-down wirebound type. This latter type facilitates the return of the empty boxes.

STORING POTATOES

The purpose of potato storage is to maintain tubers in their most edible and salable condition and to provide a uniform flow of tubers to the processing plant throughout fall, winter and spring. Good storage should prevent excessive loss of moisture, development of rots and excessive sprout growth. It should also prevent large accumulation of sugars and other constituents which result in dark-colored processed products.

After harvest potatoes usually undergo a rest period of several months during which there is little or no sprout growth regardless of environmental conditions. Following the termination of the rest period sprout growth occurs at temperatures of 40°F. or above. If storage temperatures are maintained below 40°F. very little, if any, sprout growth occurs. However, reducing sugars and sucrose accumulate in tubers in excessive quantities at temperatures below 40° to 50°F. High reducing sugar content of potatoes in conjunction with nitrogenous portions of the tubers is the cause of the undesirable dark brown color of potato chips and French fries and the browning of dehydrated potatoes during shipment or storage. It is important to have available some method of storing potatoes at 50°

to 60°F. but with little or no sprout growth, no reduction in specific gravity of tubers, no accumulation of sugars and a minimum loss in weight.

Effect of Storage on Specific Gravity of Tubers and Quality of Processed Product

Specific gravity of potatoes used for processing is of great importance. High gravity potatoes are preferred for potato chips, French fries and dehydration. On the other hand potatoes of low specific gravity are preferred for canning because they slough or fall apart less during processing than potatoes of higher gravity. Temperature and humidity of storage may have an effect on change in specific gravity of the tubers. Chippewa, Green Mountain, Katahdin, Russet Burbank and Triumph potatoes stored at a relative humidity of 83–84 per cent increased in specific gravity at both 40° and 55°F. storage (Heinze *et al.* 1952). At 90 per cent relative humidity specific gravity of tubers remained practically unchanged in storage up to six and one-half months at 40° and at 50°F. Specific gravity of potatoes increases with length of time in storage and indicates an increase in percentage of solids in the tubers (Terman *et al.* 1950). This is a result of greater loss of water by evaporation than loss of solids by respiration.

Some potatoes of high specific gravity slough or fall apart when they are cooked. This is very undesirable in the potato canning industry. Rathsack (1935) attributed this to the turgidity of the tubers. Many lots of potatoes boil to pieces badly when cooked soon after harvest but after they have been stored and lose some of their moisture this tendency decreases. Barmore (1938) showed that there was less disintegration of peeled, diced pieces when cooked if the tubers have been stored at about 65°F. for a time. When potatoes slough, the cells separate and the cell walls stretch but are not necessarily broken. In potatoes of low starch content there are insufficient granules in the cells to distort the cell walls when the granules swell during cooking (Nutting 1950). It was noted that potatoes of specific gravity 1.080 or higher and 14 per cent or more starch, sloughed, but those below these figures did not. By storing potatoes at a temperature which lowers the starch content sloughing may be reduced.

The relationship between specific gravity and sloughing depends partly on the physiological conditions and storage history of the potatoes. Factors which decrease the amount of starch per cell, such as sprout formation, storage at high temperatures such as 75°F., or low temperature (35°F.), tend to decrease amount of sloughing. Factors which retard the decrease in starch, such as dormancy or storage at 50°F., tend to

help retain the original texture and degree of sloughing (Whittenberger 1951).

Effect of Storage on Sugar Content of Potatoes

Storage Temperature and Sugar Content.—The importance of storage temperature on the processing quality of potatoes has been emphasized earlier. Potatoes stored at temperatures under 50°F. usually produce dark color chips. French fries and dehydrated potatoes are somewhat less susceptible to browning than are potato chips, but even they often darken excessively if the storage temperature is below about 45°F. Sweetman (1930) showed that chips made from tubers stored between 32° and 37°F. were darker than those made from potatoes stored at between 40° and 55°F. Others also have found that color of potato chips is most desirable when made from tubers stored at 60° or 70°F. and brown color of chips becomes more intensified as storage temperatures decrease to 40°, 36° and 32°F. (Peacock *et al.* 1931; Wright *et al.* 1936).

It has been known for many years that sugar content of potatoes increases when they are stored at comparatively low temperatures (Muller-Thurgau 1882; Appleman 1912). Appleman mentioned three processes which occur in potatoes during storage, (1) respiration, which utilizes sugars by converting them into carbon dioxide and water, (2) conversion of starch to sugar by amylolytic enzymes, and (3) conversion of sugar to starch, presumably by starch-synthesizing enzymes. As sugars increase at low temperatures, starch decreases and at high temperatures sugars decrease as a result of respiration and starch synthesis.

The amount of sugars formed during low temperature storage depends on variety, maturity and pre-storage conditions as well as temperature. The extent of sugar loss which occurs on exposure of potatoes to high temperatures also varies with variety and maturity. A large increase in total sugars, primarily reducing sugar, occurs in potatoes stored at 34° and 36°F. At temperatures of 38° and 42°F. the increase in sugar is less and at 50° and 60°F. a slight reduction may occur. Most of the reducing sugar in tubers stored at 60°F. is in the sprouts (Treadway *et al.* 1949). Wright *et al.* (1936) found the dividing line between relatively high and low sugar content occurred between storage at 50° and 40°F. Sugar content of potatoes stored at 50° and 60°F. for some time was about the same as when the potatoes were placed at these temperatures.

Unless freshly harvested potatoes have been exposed to low temperatures before harvest they contain very little sugar. During storage at low temperatures reducing sugars accumulate more rapidly than sucrose, Schwimmer *et al.* (1954). With Chippewa, Kennebec, Katahdin and Russet Burbank tubers the ratio of glucose to fructose is approximately

one at low temperatures and it increases to above two at higher temperatures. White Rose tubers tend to accumulate fructose.

Sucrose, fructose and glucose comprise the major sugars of the potato. Schwimmer *et al.* (1954) detected trace amounts of sugars in potatoes chromatographically similar in behavior to ketoheptose, melibiose, melezitose and raffinose and also inositol. Of the three principal sugars, fructose is most responsive to changes in storage temperatures. Tubers stored at low temperatures were high in fructose and fructose 6-phosphate whereas those stored at high temperatures were high in glucose and glucose 6-phosphate (Arreguin-Lozano and Bonner 1949).

Gas Storage and Sugar Content.—Increasing the CO_2 content of the storage atmosphere has an effect on the reducing sugar content of tubers. The rapid increase in reducing sugar content that occurs in tubers stored at 41°F. can be prevented by adding five per cent CO_2 to the surrounding air (Denny 1941). At 35.6°F. 20 per cent CO_2 has a greater retarding effect on reducing sugars than five per cent, but at 41° and 44.6°F. the reverse is true. At 44.6°F. 20 per cent CO_2 at first retards reducing sugar development for about 30 days and then hastens it so that after 90 days the reducing sugar content of the CO_2-treated potatoes was 3 to 4 times that of the controls, (Denny and Thornton 1942).

Delayed Storage and Sugar Content.—The sensitivity of the sugar-forming system to a given low temperature may be reduced by first placing the tubers at an intermediate temperature before transfer to the lower final temperature. When the temperature is decreased slowly the accumulation of sugars may be much reduced (Barker 1939). There were marked differences in temperature at various positions in an outdoor storage pit and these were correlated with the total sugar content of potatoes in those areas (Barker and Wallace 1946). Potatoes placed in storage at 41°F. soon after harvest accumulated reducing sugar much more rapidly than those held at 77°F. for some time after harvest before being placed in storage at 41°F. (Thornton and Denny 1941).

Sugar Content of Stored Potatoes Treated for Sprout Inhibition.—Potatoes may be sprayed in the field with sprout inhibitors or tubers may be treated with chemicals or irradiation in storage for sprout suppression (see also Chapter 6). These treatments make it possible to store potatoes at higher temperatures without excessive sprout growth. Several workers have shown that spraying maleic hydrazide on plants in the field had no influence on reducing sugar content of tubers during subsequent storage (Highlands *et al.* 1952, Kennedy and Smith 1953, Gooding and Hubbard 1956). At the end of six month's storage at 40°F., treated tubers of Katahdin and Kennebec varieties showed no difference in reducing sugar content compared with untreated tubers (Highlands *et al.* 1952). Re-

ducing sugar content of seven varieties of potatoes stored at 50°F. showed no differences between maleic hydrazide treated and untreated tubers (Kennedy and Smith 1953). Gooding and Hubbard (1956), also found that treatment of potatoes with the sprout inhibitor tetrachloronitrobenzene had no effect on reducing sugar or sucrose content during subsequent low temperature storage. On the other hand Salunkhe *et al.* (1953) report that maleic hydrazide-treated potatoes were lower in reducing sugars during storage than tubers which were not treated.

Gamma irradiation of potatoes at dosages of 10,000 to 15,000 REP completely inhibits sprout growth for a year or longer at 50°F. storage (see also Chapter 6). Sereno *et al.* (1957) found no significant difference in reducing sugars of irradiated and untreated Katahdin tubers during the first six months storage at 45°, 50° and 60°F. During the second six-months' period, however, irradiated tubers had higher reducing sugar content. Untreated potatoes stored at 38°F. had higher reducing sugar content during the first six months whereas the irradiated tubers were higher than the untreated during the second six-months' period of storage. Irradiating Russet Burbank potatoes after they had been stored for five months at 40°F. resulted in a three-fold increase in sucrose in 16 days; fructose and glucose showed smaller increases (Schwimmer *et al.* 1957). At 70°F. the levels of sucrose and glucose in irradiated tubers increased above those of the controls reaching a maximum in four days and then declining. There was no effect on fructose loss. Holding potatoes for a time at one temperature and then placing them at higher or lower temperature has a marked effect on their sugar content.

Reconditioning Temperatures.—Potatoes stored six weeks at 40°F. and then moved to 70°F. for six weeks had sugar content similar to those lots just before they were placed in storage. Potatoes originally stored at 36° and 32°F., however, and then removed to 70°F. storage still had relatively high sugar content after six weeks. When, however, potatoes were stored at 60° for six weeks and then moved to 40°F. storage for six weeks their reducing sugar and sucrose content was higher than those stored continuously at 40°F. Those stored at 50°F. then shifted to 40°F. had higher sucrose content than those held constantly at 40°F., although their reducing sugar content was less (Wright *et al.* 1936).

Effect of Storage on Starch in Potatoes

Starch content of potatoes decreases with a lowering of storage temperature through the process of starch conversion to sugars by amylolytic enzymes. Starch may increase in potatoes by conversion of sugars to starch at higher temperatures. A considerable amount of starch is lost in potatoes at storage temperatures of 34°, 36° and 38°F. Those in cold

storage for 2 to 3 months contain only about 70 per cent of their original starch. At higher temperatures the change from the original is less. After 7 to 37 weeks of low temperature storage and two weeks at room temperature, starch per cent increases, approaching the value at harvest. The total carbohydrate content of potatoes on the dry weight basis changes little in storage at 34° to 60°F. (Treadway *et al.* 1949). White Rose tubers stored at 40° F. decrease in starch content but show practically no change at 50° and 70°F. In Russet Burbank tubers, however, starch remains almost constant except a decrease after 18 weeks' storage at 40°F. and an increase at 70°F. (Schwimmer *et al.* 1954).

Regardless of storage temperatures, Sereno *et al.* (1957) found little significant difference in starch content of irradiated and nonirradiated Katahdin tubers.

Starch from potatoes stored for a long time has less gloss and the surface and form of the grains undergo a change. Starch grains of all sizes gradually decrease in size and the number of grains of small diameter increases during storage (Volksen 1943).

The change of starch to sugar at low temperatures and the subsequent partial resynthesis of starch from sugars at high temperatures may change the growth structure of starch granules sufficiently to alter the properties of the paste. This is likely to affect the quality of the starch and subsequently the texture of the cooked potato. Nutting and Whittenberger (1949) found, however, that although potatoes lost 30 per cent of their starch while in storage, this change did not alter the granule structure or the starch molecules within it sufficiently to change the swelling capacity of the granules. It also did not change the stability of the swollen granules toward dissolving, mechanical breakage or loss in volume by diffusion into the pasting medium. Paste viscosity of starch was not affected by storage of potatoes for periods up to nine months at temperatures of 34°, 42° and 50°F.

Effect of Storage on Enzymes

Potatoes contain low amylase activity and this enzyme is essentially inactive in vitro at 32°F. It appears not to be a factor in starch degradation and sugar formation at low temperatures (Arreguin-Lozano and Bonner 1949). Phosphorylase is equally active in potatoes from all storage temperatures and it does not attack starch in potatoes stored at high temperatures. Apparently this is due to the formation of an inhibitor of phosphorylase at high temperatures but which disappears at low storage temperatures (Arreguin-Lozano and Bonner 1949).

Storage time and temperature have no effect on amylose content of

TABLE 16

RATE OF RESPIRATION OF IMMATURE TUBERS DURING STORAGE[1]

Treatment No.	Sept. 26		Oct. 5		Oct. 8	Nov. 6	Dec. 7	Jan. 8	Feb. 8	Mar. 7	Apr. 22
	CO_2 per Kg. Hour Mg.	Average Temperature °F.	CO_2 per Kg. Hour Mg.	Average Temperature °F.	Mg., Carbon Dioxide per Kg. Hr.						
1[2]	18.3	65	13.0	65	12.4	6.2	2.8	1.8	1.2	1.15	1.68
2[3]	10.5	45	6.8	45	7.8	5.6	3.0	1.9	1.2	1.08	2.07
3[4]	22.8	65	19.8	65	19.0	6.6	3.0	2.0	1.2	1.15	1.80
4[5]	15.6	45	7.2	45	7.9	5.9	3.2	2.1	1.3	1.06	2.07
Average temp. °F.	....	...	....	...	58	50	43.5	40	36.5	37.5	39

[1] From Smith (1933).
[2] Carefully handled; warm, moist storage for 8 to 12 days.
[3] Carefully handled; cool, moist storage for 8 to 12 days.
[4] Normally handled; warm, moist storage for 8 to 12 days.
[5] Normally handled; cool, moist storage for 8 to 12 days.

TABLE 17

RATE OF RESPIRATION OF MATURE TUBERS DURING STORAGE[1]

Treatment No.	Sept. 26		Oct. 5		Oct. 8	Nov. 6	Dec. 7	Jan. 8	Feb. 8	Mar. 7	Apr. 22
	CO_2 per Kg. Hour Mg.	Average Temperature °F.	CO_2 per Kg. Hour Mg.	Average Temperature °F.	Mg., Carbon Dioxide per Kg. Hr.						
5[2]	15.2	68	12.4	68	12.0	5.8	2.2	1.2	0.90	0.88	1.68
6[3]	9.0	46	5.8	46	6.3	4.8	2.6	1.3	0.91	0.98	2.08
7[4]	19.8	68	17.4	68	16.8	6.2	2.8	1.4	1.3	1.28	1.78
8[5]	13.2	46	6.3	46	6.9	5.1	3.0	1.5	1.3	1.25	1.56
Average temp. °F.	....	...	....	...	56	54	42	40	36.5	37	41

[1] From Smith (1933).
[2] Carefully handled; warm, moist storage for 8 to 12 days.
[3] Carefully handled; cool, moist storage for 8 to 12 days.
[4] Normally handled; warm, moist storage for 8 to 12 days.
[5] Normally handled; cool, moist storage for 8 to 12 days.

starches in potatoes nor on their amylose-amylopectin ratio (Schwimmer *et al.* 1954).

Effect of Storage on Respiration of Potatoes

Potatoes shrink or lose weight during storage. This weight loss is comprised of water loss from the tubers, carbon dioxide loss and decay losses as a result of rot organisms. The amounts of these losses are determined by storage conditions such as temperature, humidity, evaporating power of the air, composition and movement of the air and the maturity and condition of the potatoes at time of storage.

Temperature and Respiration.—Respiration rate of potatoes increases with increase in temperature. Hopkins (1924) has shown that the minimum rate of respiration of potato tubers occurs at a temperature of 37.4°F. and that the rate of respiration of tubers stored at 32°F. is greater than that of tubers stored at 40°F.

Maturity and Respiration.—The rate of respiration may be closely linked with the physiological shrinkage during storage. Immature tubers and potatoes immediately after harvest have higher rates of respiration than mature tubers or those that have been harvested for some time (Smith 1929 and 1933). Potatoes which are carefully handled to avoid bruising during harvest and storage respire at a lower rate than potatoes which are handled less carefully (Smith 1933). Lutman (1926) found a large increase in respiratory rate of potatoes on the second or third day after wounding followed by a gradual return to normal rate. Some of this apparent increase in rate of respiration, however, may be due to facilitating the escape of carbon dioxide by injury to the periderm of the potato. Carbon dioxide builds up to a rather high concentration in the tissues of the potato (Magness 1920; Smith 1929). Because of this accumulation of carbon dioxide in tuber tissue, rates of respiration may appear to be different in tubers in closed containers compared with those with continuous removal of exhaled gas (Denny 1946A and B; 1947).

Smith (1929) showed that dormant tubers stored under conditions that increased respiration had lower oxygen content in their tissues than those with lower respiration rates. Burton (1950) found no marked change in oxygen content of tubers during storage.

Composition of Atmosphere and Respiration.—The composition of the atmosphere in storage may affect the rate of respiration, loss of weight and quality of tubers. When oxygen concentration of the atmosphere is lowered from 20.9 per cent to 15 per cent, respiration rate of tubers is depressed about five per cent. At 18 per cent oxygen there is no effect (Denny 1948). Kidd (1919) reported that oxygen is harmful to the

potato in concentrations above 5–10 per cent; 80 per cent oxygen killed tubers in 4 to 5 weeks.

Crook and Watson (1950) detected carbon dioxide concentrations of 0.06 to 0.86 per cent in the atmosphere of outdoor pits of potatoes. Carbon dioxide accumulation and oxygen depletion in outdoor pits is too small to produce effects of practical importance on the storage behavior of potatoes.

Potato tubers transferred from anaerobic conditions to air show a characteristic quick increase in the rate of CO_2 production above the respiration of control tubers, followed by a decrease to the level of control tubers. This high rate of CO_2 production is associated with a rapid disappearance of lactic acid which has accumulated during the period in nitrogen (Barker and Saifi 1952 and 1953).

There also is an increase in the sugar content under anaerobic conditions followed by its decrease under aerobic conditions. The changes in CO_2 production are attributed to corresponding alterations in the concentrations of pyruvic acid and of the keto-acids of the Krebs cycle (Barker and Saifi 1953). It is thought that lactic acid and sugar contribute to the CO_2 production through the common intermediate, pyruvic acid.

Potatoes kept in nitrogen 8 to 12 days accumulate lactic acid. When these tubers are transferred to air the accumulated lactic acid is oxidized to pyruvic acid which is then further metabolized or respired. This results in an initial increase in pyruvic acid followed by a decrease as its rate of utilization exceeds the rate of formation.

The characteristic increase and subsequent decrease in the rate of CO_2 output in air following storage in nitrogen appears to be primarily related to the respiration of pyruvic acid, possibly via the keto-acids of the Krebs cycle (Barker and Mapson 1953). Carbon dioxide output of tubers in air following storage in nitrogen is derived partly from the accumulated lactic acid and partly from sugar. Lactic acid probably is first oxidized to pyruvic acid which might then be transformed into other acids possibly via the Krebs tricarboxylic cycle (Krebs and Johnson 1937; Krebs 1952). Sugar probably is glycolyzed to pyruvic acid so that the CO_2 output, derived either from lactic acid or from sugar, would be produced by decarboxylation of pyruvic acid and of the keto-acids of the Krebs cycle (Barker and Saifi 1953).

The form and magnitude of the after effect in CO_2 output following a period of anaerobiosis are markedly affected by the duration in storage since harvest (Forward 1953).

It was first reported in 1928 that treating potatoes with ethylene chlorhydrin and ethylene dichloride produced a similar response, i. e. a rapid increase in CO_2 output followed by a decrease (Smith 1928). These changes in CO_2 output are associated with a large decrease in the content of citric acid (Miller *et al.* 1936). There is also an increase, followed by a slower decrease, in the sugar content, but the peak value in the sugar changes is attained after the CO_2 output has begun to decrease. The time relations of the changes in CO_2 output, in sugar and in a particular organic acid are similar to those which occur in air after nitrogen, but instead of the decrease being in lactic acid there is a marked loss of citric acid (Barker and Mapson 1953).

Instead of loss of citric acid being due to its consumption in respiration it may be that it is converted into the keto-acids, oxalo-succinic and x-ketoglutaric. The changes in the rate of CO_2 output would thus be ascribed to corresponding changes in the content and/or the rates of decarboxylation of these keto-acids.

Change in Temperature and Respiration.—When potatoes are transferred from lower to higher temperatures there is an increase in respiratory activity usually of short duration (Kimbrough 1925; Smith 1933). Appleman and Smith (1936) state that the sugars which accumulate at low temperatures are not responsible for the initial high respiration rate when they are placed at higher temperatures. Respiratory activity of potatoes in storage rapidly decreases following harvest. Six weeks after harvest potatoes at 40°F. storage have a low respiration rate and maintain this while the tubers are dormant. As sprout growth begins and especially with an increase in storage temperature, respiratory activity increases (Smith 1933).

Loss in weight of potatoes in storage due to respiration is very small in comparison with the loss in weight caused by evaporation of water. In common storage during a seven-months' period shrinkage as a result of respiration was only 0.51 per cent whereas shrinkage due to water loss was 5.71 per cent (Smith 1933).

Varieties.—Schulz (1926) found that the rate of uptake of oxygen by tubers of late varieties was greater than in early varieties. Individual tubers of the same variety show considerable variation in respiratory activity.

Sprout Inhibition.—Respiration rate of potatoes which receive dosages of 5, 15 and 25 kilo-REP of gamma irradiation decreases about 30 per cent the first day following treatment. The second day it increases to 60 per cent above the untreated tubers. This is followed by a decline until during the thirteenth week of storage the irradiated tubers respire about five per cent less than the untreated (Brownell *et al.* 1957). Irradiation of

Sebago and Pontiac tubers with 5,000–15,000 REP causes less change in respiration than higher dosages (Gustafson *et al.* 1957). Salunkhe *et al.* (1953) reported that tubers from maleic hydrazide treated vines had a greatly reduced rate of respiration during storage and conditioning.

Effect of Storage on Nitrogen Metabolism in Potatoes

The protein content of potatoes is rather low, ranging from approximately 1.5 to 2.5 per cent of the fresh weight. Storage conditions, especially temperature, may have an effect on the proportions of the nitrogenous fractions in tubers. Stuart and Appleman (1935) found slightly less change in protein nitrogen of tubers stored at 35.6° to 37.4°F. than at room temperature. There are practically no differences, however, in the non-protein, alpha amino nitrogen, basic nitrogen, amide nitrogen and residual nitrogen of potatoes stored at these two temperatures. During the rest period, the first 60 days of storage, Tagawa and Okazawa (1955) found no change in the various nitrogen fractions of potatoes. During the next 40 days, the rest-end stage, the soluble nitrogen, especially amide nitrogen increased in the terminal bud and cortex with a corresponding decrease in the protein of the pith. During the sprouting stage, the next 30 days, protein nitrogen and soluble nitrogen increased, especially amide nitrogen of the terminal bud and a corresponding decrease of protein nitrogen in other parts of the tuber. Shallenberger (1955) reported highest total nitrogen in potatoes stored at room temperature and lowest in those at 32° and 40°F. Total nitrogen also increased with length of storage from 2 to 8 months. Protein nitrogen and total soluble non-protein nitrogen in tubers stored at 40° and 50°F. increase with length of storage.

Potatoes stored at 40°F. from 2 to 8 months are higher in amino acids and basic nitrogen than those stored at 50°F.; the amount also increases with length of storage. Potatoes stored at room temperature have a higher content of amide nitrogen than those stored at 32°, 40° and 50°F. Habib and Brown (1957) report that cold storage slightly affects the amount of basic amino acids in tubers, while conditioning at 75°F. results in their disappearance. The same authors (1956) found no significant differences in free amino nitrogen of tubers before and after storage at 40°F., but after several weeks of reconditioning at 75°F., the amount was greatly reduced.

Effect of Storage on Ascorbic Acid in Potatoes

The potato is considered to be a good source of vitamin C or ascorbic acid. During storage, however, ascorbic acid content of tubers decreases.

Influence of Storage Temperature on Ascorbic Acid Content.—Ascorbic acid content decreases when freshly dug immature or mature potatoes are stored at 50° to 59°F. (Olliver 1936; Pett 1936; Scheunert *et al.* 1937;

Smith and Paterson 1937). At lower temperatures loss of ascorbic acid is even greater. Storage at 41°F. results in faster disappearance than at 59°F. (Mayfield *et al.* 1937; Rolf 1940). At temperatures as low as 32°F. the loss is more rapid than at 50°F. (Karrika *et al.* 1944; Murphy 1946). However, Olliver (1936) found slower rates of loss at 32° and 31° than at 50°F. or at room temperature. Ascorbic acid increases when potatoes, previously held at 50°F. or higher, are transferred to 32°, 34° or 41°F. (Kelly and Somers 1949; Barker 1950).

Changes in Ascorbic Acid Content at 50°F. and Below.—Transferring potatoes to temperatures below 50°F. results in increases in ascorbic acid, which, though only temporary are often considerable in amount and in length of time. The increase, in general, commences sooner the higher the temperature to which the potatoes are transferred. The increase, however, continues longer and to a higher maximum the lower the temperature. Thus largest increases occur at 30.5° or 30.9°F. and the smallest at 41°F., with 34°F. intermediate (Barker and Mapson 1950). The decreases, however, are faster at the low temperatures than at 50°F. so that ascorbic acid content at the lower temperatures ultimately falls below those at 50°F.

The developmental state of the tubers influences the ascorbic acid reactions to temperature to a greater degree than the year to year variations due to differences in type of seed, soil and climate (Barker and Mapson 1950).

Changes in Ascorbic Acid at 50°F. and Higher Temperatures.—There are two markedly different forms of response in changes in ascorbic acid content at temperatures above 50°F., which are associated with differences in the developmental state of the tubers. With potatoes stored for six months or longer at 50°F., the transition to 77°F. initiates a slow increase in ascorbic acid. With freshly dug immature potatoes the increase in temperature appears at first only to accentuate the rate of decrease and later by a marked diminution in the rate of fall of ascorbic acid at 77°F. so that the content is ultimately maintained above that at 50°F. Ascorbic acid content probably is the result of those reactions producing the vitamin and those causing its losses (Barker and Mapson 1950).

Changes in Ascorbic Acid Content During Storage at 50°F.—The most rapid and greatest total decrease at 50°F. storage occurs in the most immature tubers, those harvested earliest; the least rapid and least total loss occurs in the mature, late harvested tubers. Intermediate harvests are intermediate also in loss of ascorbic acid. The metabolic condition of the tuber when dug exerts a very marked effect on the rate of disappearance of ascorbic acid in storage. Although rate of ascorbic acid loss from

mature tubers is less than from immature tubers, it is appreciable. During 3 to 4 months' storage losses are 50 per cent; the rate of fall becomes progressively slower the longer the potatoes are held in storage (Barker 1950).

Ascorbic Acid and Sugar Content of Potatoes in Storage.—Initial hexose and sucrose contents of potatoes are highest at the early harvests and decrease with advancing maturity (Barker 1950).

During storage at 50°F. the hexose content rises in tubers of each stage of maturity; the earlier the harvest, the greater the increase in hexose content. This increase in hexose is a result of increases in both fructose and glucose. Thus the drifts of hexose and of ascorbic acid are in opposite directions for at least 30 days in storage at 50°F.

For sucrose content the relation is quite different. In immature tubers the sucrose content is high at time of digging. A marked reduction occurs in immature tubers immediately after digging and continues for at least 100 days although becoming progressively slower. The decrease in sucrose closely resembles corresponding decreases of ascorbic acid in the early harvested tubers. Slight increases in sucrose content of mature harvested potatoes occur for a 10 to 20-day period following harvest. This is followed by gradual decreases in sucrose and this decrease parallels the decrease in ascorbic acid (Barker 1950).

A close correlation, therefore, exists between the ascorbic acid content and the sucrose concentration of potato tubers. One interpretation of the significance of this correlation is that ascorbic acid and sucrose are formed from a common precursor. An alternative view is that both the formation of ascorbic acid and the synthesis of sucrose result from similar metabolic conditions. Sucrose content is only one of several factors which appear to influence the ascorbic acid content of potato tubers. Respiration of potato tubers is closely correlated with the content of sucrose. The observed relation between ascorbic acid and sucrose may thus reflect an interaction between the respiratory mechanism and the formation or loss of ascorbic acid (Barker 1950).

Effects of Sprouting.—Sprouting does not appear to influence the course of the fall in ascorbic acid (Barker and Mapson 1950), and no increase in ascorbic acid occurs at sprouting. It was shown (Guthrie 1937) that the ascorbic acid increase in sprouting of potatoes reported by Pett (1936) probably was due to the wounding of the tubers by cutting and not to their sprouting.

Effect of Storage in Air, in Nitrogen and in Pure Oxygen.—Barker and Mapson (1952) stored potatoes in nitrogen and found that the content of ascorbic acid was almost stabilized by the exclusion of oxygen. This

suggests that there is little, if any, formation or loss of ascorbic acid i the absence of oxygen.

Pure oxygen, however, appears to be toxic to potatoes and the amou of ascorbic acid decreases nearly to zero under these conditions.

Irradiation.—Gamma irradiation of potatoes at a dosage of 15,000 RE results in a decrease in ascorbic acid content below the untreated fo the first seven months' storage at 38°, 45° and 50°F. and for four month at 60°F. Beyond seven months' storage there was very little differenc between treated and untreated tubers (Sereno *et al.* 1957). Irradiatio sharply decreases the reduced ascorbic acid content of potatoes (Browne *et al.* 1957).

Storage Conditions Causing Physiological Breakdown in Potatoes

Proper control of temperature and sufficient ventilation or air circula tion in storage will prevent the occurrence of such troubles as blackhear freezing or chilling, mahogany browning and stem end browning.

Blackheart.—This is a fairly important storage and transit tuber defe especially in the processing industry. This breakdown occurs as a resu of suboxidation. Insufficient oxygen reaches the interior of the tuber t supply normal metabolism and respiration. Under normal conditions o an adequate supply of air, either in transit or in storage, this trouble doe not occur unless temperatures are 90°F. or higher. At high tempera tures, oxygen is needed for respiration in greater quantities than it possible for air to supply it by entering the potato and moving to th interior. The internal symptoms are dark gray to purplish or black dis coloration near the center of the tuber. This defect may be prevented b supplying adequate air by ventilation and by keeping temperatures belov 80°F. (Ramsey *et al.* 1949).

Low Temperature Injury.—Tuber injury from low temperature ofte occurs in the field before or during harvest as well as in transit and storage *Freezing injury* may appear as internal discoloration after prolonge storage of potatoes at temperatures several degrees above their freezin point. Some varieties, however, do not show injury even when held a low as 29°F., the freezing point of most potatoes. Tubers that are froze solid collapse upon thawing, become soft and exude their juice. Milde types of freezing show up as dry, gray or bluish gray patches under th skin or as a darkening of the vascular ring. Sometimes a netlike patter of dark spots occurs scattered throughout the tissue.

It is well to take note of where the freezing injury occurs in the truc car or storage. If it is found predominantly on the floor, against a side o end wall or near a door or ventilator this may help one in identifying th trouble. Potatoes may be chilled without showing any visible symptom

However, sugars accumulate at these low temperatures making it much more difficult to recondition the potatoes for processing.

Low temperature injury may be avoided by harvesting potatoes before soil temperatures go below 40°F. and by protecting them during transit and storage from temperatures lower than 40°F. Good insulation, air circulation and artificial heating during transit and storage should prevent this trouble (Ramsey *et al.* 1949).

Mahogany browning is a form of low temperature injury that affects Chippewa and Katahdin tubers. This internal reddish-brown discoloration may occur in irregular patches anywhere in the tuber. The affected tissues are of normal firmness and consistency but are unfit for processing. This defect develops when tubers of Chippewa and Katahdin varieties are stored near 32°F. for 20 weeks or longer. In northern areas it is likely to first appear in March in parts of the bin or storage that have been at low temperatures. Although Sebago tubers are not susceptible to mahogany browning they may develop a blackish discoloration of the flesh when stored at 30° to 32°F. for 20 weeks. Mahogany browning may be avoided by storing Chippewa and Katahdin tubers at 38°F. or above (Hilborn and Bonde 1942).

Stem-End Browning.—This defect is recognized as a dark brown or blackish discoloration that develops at the stem end of the tuber, primarily in Green Mountain and Irish Cobbler varieties (Ramsey *et al.* 1949). Ordinarily it does not extend deeper than one-fourth to one-half inch from the stem end. Although the cause of stem-end browning is unknown there is a marked relation between storage temperature and the development of stem-end browning in susceptible tubers. The greatest amount occurs when tubers are stored for about 100 days at 50°F. The most important period is the first several weeks of storage. By conditioning susceptible potatoes for 60 days at either 70° or 32°F., subsequent development of this trouble is practically inhibited. This is the best control measure known.

Greening.—This is caused by exposure of tubers to natural or artificial light in the field, in transit or in storage. The green color tissue is usually accompanied by the formation of solanine, an alkaloid that may be poisonous if consumed in sufficient amounts. Such potatoes have a bitter taste and when processed, may also result in a less attractive product because of the green color. Russet varieties usually green less than white skinned tubers when given the same light exposure. To avoid greening in storage, lights should not be left on any longer than is necessary. Greened portions of tubers should be removed by peeling or trimming, so that they do not affect the processed product.

POTATO STORAGES

Most modern potato storages are of the bank, above-ground, or belov ground type with a superstructure. There is a trend in many areas fro the bank and below-ground type to the above-ground storage. Mo storages built by potato processors are of the above-ground type and mar of them comprise a portion of the processing plant. The rather consta temperature of the earth in bank and below-ground types of storag helps avoid storage temperature fluctuations resulting from variatio in weather. With modern materials and methods, however, it is possib to maintain adequate storage conditions in above-ground storages.

Modern storages are of masonry, wood frame or prefabricated meta Walls and other members should be strong enough to withstand loads t which they will be subjected. They should be sealed with moistur vapor-proof materials to prevent moisture loss and they should be i sulated to prevent excessive flow of heat through the walls and ceilin Provision should be made for adequate ventilation, air circulation an heating when necessary. Some modern storages are being provided wit refrigeration. Attention also should be given to the operation of potat handling equipment.

Storage capacity may be computed as follows: LxWxH ÷ 1.43 = bushels capacity, when L, W and H represent in feet, respectivel the length and width of the storage and depth of the potatoes.

Wall Construction

This should be such that the wall strength will be sufficient to witl stand lateral pressures produced by the potatoes and also by the wind ar outside banked soil. Lateral potato pressures are 60 lbs. per squar foot at 8 foot depth and 100 lbs. per square foot at 16 foot depth. I masonry construction this is provided by placing reinforcing ba both vertically and horizontally at specific points. Care should l taken to provide ties and sway braces if the walls are of frame constru tion.

To eliminate condensation on the insulating material in the wall c ceiling a water vapor barrier should be installed on the inside surface c the insulation.

Roof Design

Roof trusses may be of wood or metal. Unsupported roof spans of 5 feet or more are possible with trussed rafters prefabricated on the groun and raised into position. Diagonal ties and braces at specific points on tl roof are necessary for reinforcement.

Insulation

To control rate of heat flow through walls and ceiling, thermal insulation should be used. The quality of the insulation varies with thickness, density, and composition of the material. Insulation materials that absorb moisture, cause fire hazards, rot or attract vermin should not be used.

Some of the most efficient insulation materials per unit of thickness in blanket or bat form are (1) kapok between burlap or paper, (2) cotton insulating bat and (3) chemically treated wood fibers held between layers of strong paper. Some of the best materials as loose fill are (1) rock wool, (2) glass wool fibers, (3) fibrous materials made from slag and (4) fibrous material made from dolemite and silica. Most efficient slab insulation materials are (1) corkboard and (2) styrofoam (Bennett *et al.* 1958).

Walls often are of concrete block or masonry construction. They possess a low degree of insulating value; a twelve-inch concrete block made with sand and aggregate has the insulating qualities of one-third inch of glass wool or rock wool. Two to three inches of good insulating material should be added to the concrete blocks to obtain the necessary protection. A coat of plaster or exterior grade plywood may be placed over the insulating material to protect it and the vapor barrier.

In frame construction insulating bats, slabs or boards may be used by tacking them to the studs or outside sheathing with vapor barrier material on the inside storage side of the material. An air space between the vapor barrier and the inside sheathing adds additional insulation.

Three inches of rock wool or its equivalent is recommended for insulating storages of metal construction.

If condensation of moisture on the ceiling is troublesome it is recommended that more insulation be installed. Sometimes ceiling condensation can be avoided by substituting a darker ceiling for bright metallic or reflective materials. The dark material absorbs more of the heat given off by the potatoes and is not likely to cool the air coming in contact with it to the point of condensation.

Floor Construction

Poured concrete floors make better work floors than those of earth, make it easier to use handling equipment and render possible subsurface ventilating ducts built in as a portion of the floor. Concrete floors should be reinforced.

Air Ducts

The ventilation duct layout pattern may be of several designs. Whatever the pattern of ducts, they should be 20 inches in width if potatoes are to

be stored in bulk, so that potato unloading equipment fitting into the du may be used. Most standard conveyors are 16 inches wide. Uniformit of air distribution is of first importance. The recommended spacing f delivery ducts is ten feet on centers, although they may range from 8 t 12 feet.

Duct size is determined by the volume rate of air delivered at a spec fied velocity; recommended duct velocity is 1000 feet per minute.

Floor ventilating ducts should be wide and deep enough to assure un form air delivery throughout the storage area. Depth of the duct shoul be varied to permit uniform distribution of air throughout its entire lengt In other words it should become progressively shallower as it gets farthe from the fan or source of air. This can be done with steps at 15-fo intervals or with a continuous slope (Boyd and Layer 1952). Recom mended depth for floor delivery ducts are given in Table 18. Slatted to of the ducts may be made of 2 × 4 or 2 × 6-inch lumber, which indi vidually or in sections fit in place in recessed slots of the concrete floo These may be removed as the potatoes are taken from storage with th bin unloader.

Above-floor delivery ducts can be used in storages which are alread constructed and have good concrete floors. In this way the ducts may b used when potatoes are stored in bulk and removed when potatoes a stored in sacks or crates on pallets or in pallet boxes. Above-floor duc should not be spaced wider than ten feet on centers and potatoes shoul not be stored more than ten feet deep over them. Lumber, 2 × 12 inche makes good sides for these ducts. Slatted tops of these ducts may be 2 × 4 or 2 × 6-inch lumber. Table 19 gives recommended widths f twelve-inch deep above-floor ducts.

If potatoes are to be stored in bags or crates either individually or o pallets or in large pallet boxes or even in bulk, the entire floor may b covered with a slatted false floor. This may be in sections and removab as the potatoes are taken out. The use of palletized one-ton slatted solid side boxes is proving effective for semi-bulk handling. When slatte false floors are used it is not necessary to have air delivery ducts. A may be introduced under the slatted floor from a delivery duct runnin the length of one wall. The supports for the slatted floor must then ru at right angles to the side wall duct to allow air movement under th false floor.

Ventilating Potato Storages

Either propeller or centrifugal fans are satisfactory for ventilatin potato storages. Propeller fans are light in weight, require small spa for installation and are less expensive than centrifugal fans that deliv

TABLE 18

RECOMMENDED DEPTHS IN INCHES FOR DUCTS 20 INCHES WIDE[1]

Distance from Small End of the Duct, Ft.	8-Ft. Duct Spacing			10-Ft. Duct Spacing			12-Ft. Duct Spacing		
	Depth of Potatoes 8 Ft.	10 Ft.	12 Ft.	Depth of Potatoes 8 Ft.	10 Ft.	12 Ft.	Depth of Potatoes 8 Ft.	10 Ft.	12 Ft.
0 (sloped ducts)	3.0	3.0	3.5	3.0	3.5	3.5	3.5	3.5	3.5
0–15	5.5	6.0	7.0	6.0	7.5	8.0	7.0	8.0	8.5
15–30	8.0	9.0	11.0	9.0	11.5	12.5	11.0	12.5	13.5
30–45	10.5	12.5	14.5	12.5	15.0	17.0	14.5	17.0	18.5
45–60	13.5	15.5	18.0	15.5	19.0	21.0	18.0	21.0	24.0
60–75	16.0	18.5	21.5	18.5	22.5	25.5	21.5	25.5	29.0
75–90	19.0	22.0	25.0	22.0	26.5	29.5	25.0	29.5	34.0
90–105	21.5	25.0	28.5	25.0	30.0	34.0	28.5	34.0	39.0
105–120	24.0	28.0	32.0	28.0	34.0	38.0	32.0	38.0	44.0

[1] From Boyd and Layer (1952).

TABLE 19

RECOMMENDED WIDTHS IN INCHES FOR ABOVE-FLOOR DUCTS 12 INCHES DEEP[1]

Distance from Small End of the Duct, Ft.	8-Ft. Duct Spacing			10-Ft. Duct Spacing	
	Depth of Potatoes 8 Ft.	10 Ft.	12 Ft.	Depth of Potatoes 8 Ft.	10 Ft.
0–15	9	10	11	10	12
15–30	11	16	19	16	21
30–45	19	22	27	22	28
45–60	24	30	33	30	35
60–75	30	34	41	34	42
75–90	35	42	48	42	49
90–105	41	48	53	48	56
105–120	45	51	60	51	62

[1] From Boyd and Layer (1952).

equal amounts of air. If a centrifugal fan is preferred, the lighter weig fan meets the requirements for potato storages.

Potato storages for processing potatoes should be well ventilated an the air should be well circulated. Ventilation is used primarily for th control of temperature and humidity and to provide adequate oxygen fo the respiring tubers. Various methods of ventilation may be used rangin from manually operated doors or vents to automatically controlled a circulating equipment. Control of temperature and ventilation is mo important for processing potatoes than those for fresh market. Aut matic controls are highly desirable.

In general, bins should be smaller than for table stock potatoes, n more than 10 feet wide and the potatoes not more than 12 to 14 feet dee In order to prevent potatoes from being in an area of poor circulation is recommended that the lower part of the bin side walls be tapere toward the center of the bin floor. With air ducts in the floor 20 inche wide and the proper depth, depending on their length, running lengt wise of the bin, air movement from the duct up through the pile is a sured. Thus, the pile is warmed up or cooled off as rapidly as possible an excess moisture is removed. With constantly recirculated air there a no dead air spots nor any temperature stratification in the bin. Air taken from near the ceiling and forced through the duct system belo the bin floors. Warm air when needed is best brought in at 70° to 80°F from a heated room adjoining the storage by the use of a thermostat co trolling a damper motor. Heat may also be supplied by gas or electr heaters on the walls or hung from the ceiling. Some successful storage used primarily for reconditioning potatoes in processing plants, are heate with radiant pipes in the concrete floor or with steam or hot water pipe along the walls.

A cooling action thermostat and time clock may operate an exhaust a system which brings in outside air when lower temperatures or an a change is desired. Other methods of ventilation which may be used a the (1) two-positioned damper control ventilation and (2) proportio ing ventilation control. In the **two-positioned damper control ventil tion system** the fan, together with a housing and damper is arranged t bring in and circulate cooler outside air in a storage and exhaust warme inside air or to recirculate the air within a storage. The differentia thermostat allows ventilation only when outside air is cooler than th potatoes. The minimum thermostat causes the damper to move to position that stops ventilation and allows recirculation of storage air whe ever the ventilating air first touching the potatoes has reached a set mir mum temperature.

Proportioning ventilation control system makes use of a multiposition damper, rather than a two-position damper. When the outside air is warmer than the maximum temperature of the potatoes the storage air is recirculated. When the outside air temperature falls below the maximum potato temperature, outside air is used to ventilate and cool the storage. As the temperature of the outside air falls, the damper is turned to a partially closed system and therefore, the storage air is mixed with outside air to maintain the desired temperature (Haynes 1954).

METHODS OF STORING POTATOES

Curing

Immediately after harvest when potatoes are first placed in storage it is well to stimulate wound healing of the tubers. Growth of the new skin or periderm is hastened under conditions of 50° to 60°F. and high humidity. This results in healing of any bruised, skinned or cut portion of tubers and also stimulates continued thickening of the periderm on all uninjured surfaces. This reduces moisture and weight loss and resultant shrivelling and also the danger of rot by preventing the entry of fusarium or other storage rot organisms. At a temperature of 55°F. and 75 to 85 per cent relative humidity, suberization occurs in 5 to 7 days (Smith 1933).

If field frost or much late blight rot is present in the field, it often is better to keep the temperature at about 40°F. since the higher temperatures may also stimulate infection and decay of the tubers. Lower humidity also is desirable under these conditions to dry the surfaces of potatoes and reduce spread of rot.

After this preliminary period it is best to adjust to the desired temperature for the remainder of the storage time. Humidity should be maintained at 75 to 90 per cent. The lower the humidity the longer the tubers will remain without sprouting but the greater the shrinkage from water loss.

Reconditioning

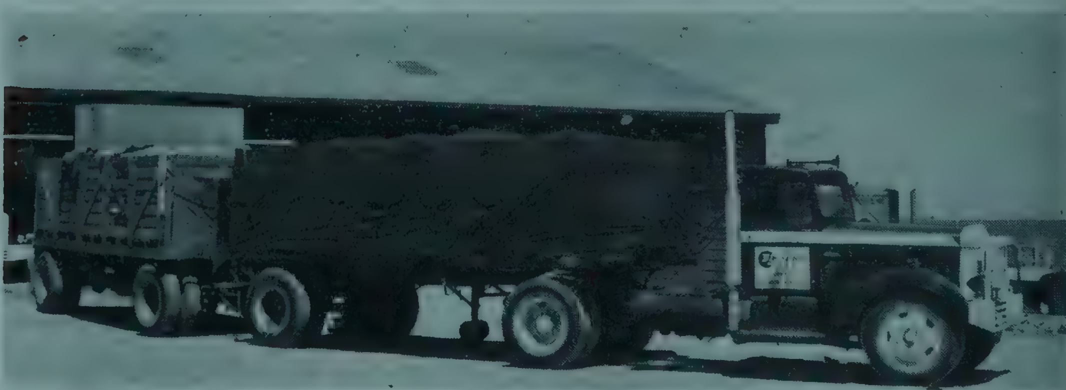
Before processing it is necessary to recondition potatoes which have been stored for several months at temperatures below 50°F. With some varieties, and especially with immature potatoes, reconditioning is needed even though storage temperatures have never been below 50°F. Reconditioning is accomplished by supplying heat to potatoes in the place where they have been stored up to this point or of removing them to a heated area. *Temperatures* should be maintained between 60° and 80°F. until frying tests indicate that the potatoes will make light color chips or French fries or until the semi-quantitative picric acid reducing sugar test indi-

cates the desired level of reducing sugars. *Relative humidity* should be maintained between 75 and 90 per cent. Lower air humidities may result in large moisture loss from tubers and resultant shrivelling. Smith (1956) has shown that relative humidity of the air, between 40 and 90 per cent, in conditioning rooms has little effect on rate or extent of conditioning.

Provision also should be made for good *circulation of air* through the potatoes and an exchange of air if temperatures get above 80°F. or if the storage is fairly air-tight.

Storage Containers

Potatoes for processing are stored in bulk, 100-lb. burlap bags, small crates and pallet-boxes. The present trend is toward pallet-boxes for in-plant handling and storage. These boxes are constructed of wood, some of knock-down type, and hold 1200 to 2500 lbs. of potatoes. The trend in sack storage is away from individual sack handling to that of skid-type pallets holding as many as 24 sacks. With hand lift or fork-type industrial lift trucks, potatoes in pallet boxes and those in bags on pallets, can be



Courtesy of Granny Goose Foods

FIG. 38. DURING TRANSIT POTATOES IN PALLET BOXES ARE PROTECTED FROM SUN AND WIND BY TARPAULIN COVERS

handled with less manual labor and less injury to the tubers. In some instances pallet boxes are filled directly from the harvester in the field and placed in storage with no further handling or injury. Some boxes are filled at the packing shed and others are filled at the processing plant by removing potatoes from burlap bags in which they are shipped (Figs. 38 to 42).

It is possible to utilize more vertical space in the potato warehouse with box than with sack storage. Boxes may be stacked any height to within a short distance from the ceiling without additional weight being placed on the tubers near the floor. The practical limit of vertical storage in sacks is from 5 to 8 sacks in height.

Courtesy of Red Dot Foods, Inc.

FIG. 39. POTATOES IN BULK BODY TRUCKS WITH SELF-UNLOADING CONVEYOR IN THE BOTTOM, BEING UNLOADED AT THE PROCESSORS STORAGE HOUSE

Courtesy of Red Dot Foods, Inc.

FIG. 40. WIREBOUND PALLET BOXES OF ONE-TON CAPACITY STACKED TWO TIERS HIGH IN A RECONDITIONING ROOM

Note that wood strips in sides run vertically.

Courtesy of Morton Foods

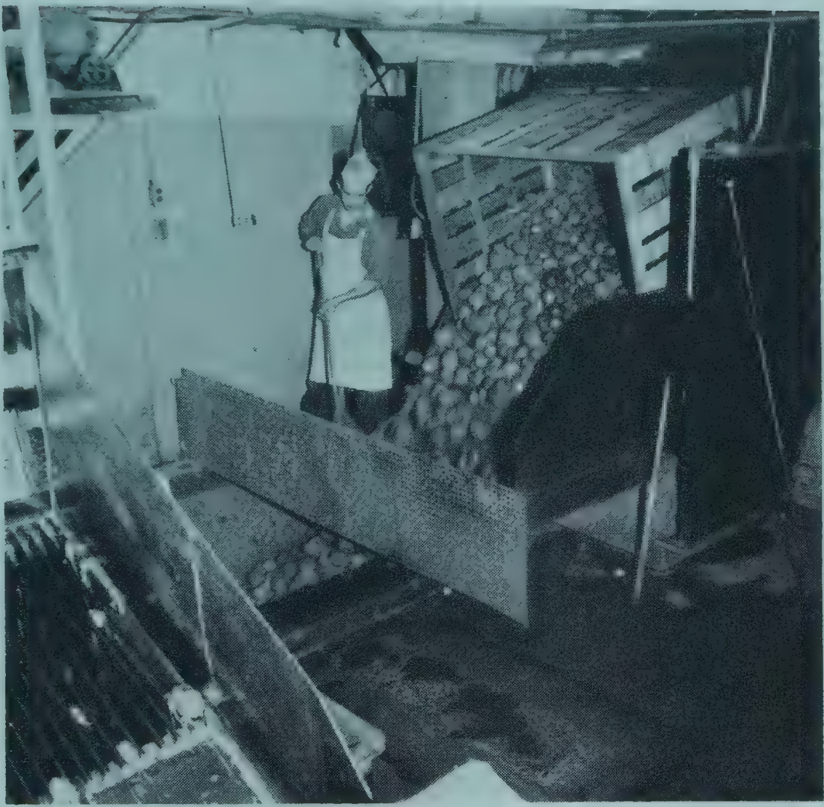
FIG. 41. POTATOES STORED IN COLLAPSIBLE CRATES OF ONE-TON CAPACITY IN A CHIP PROCESSOR STORAGE HOUSE

Note that wood strips in sides run horizontally. Fork lift truck stacks crates three tiers in height.

Box-type storage also renders it easy to maintain air channels for ventilation through the potatoes and enables the operator to quickly detect and remove any trouble spots which may develop in the tubers.

In bag-type storage, rots cause burlap deterioration with the resultant problems of loose tubers and necessity for rebagging. Where pallet boxes have been used for potato storage in the chip industry it has been found that tuber decay can be more easily controlled and handled than in other types of storage (Kennedy 1956). The tendency is for the infected tubers to dry up and the spread of decay between tubers is minimized.

Box-type compared with bag storage also reduces the amount of bruising due to handling. Goldstein (1955) found that after one month storage, potatoes in boxes showed practically no bruising. Those in burlap bags had from 25 to 60 per cent with some type of handling injury. Injuries of this type require more labor in preparation for processing and also in greater peeling and trimming loss. Kennedy (1956) found that



Courtesy of Red Dot Foods, Inc.

FIG. 42. A MECHANICAL DUMPER EMPTYING A ONE-TON PALLET BOX OF POTATOES INTO THE POTATO CHIP PRODUCTION STREAM

total shrinkage of potatoes in burlap bags from September to February was 11.5 per cent and in pallet boxes it was 8.0 per cent.

Losses in Weight in Storage

The loss in weight of potatoes in storage is dependent upon their condition at time of storage and the environment in the storage house. The factors influencing weight loss are (1) stage of maturity of the potatoes at time of harvest, (2) injury during harvesting and storing, (3) storage temperature and humidity during a short time after harvest, (4) temperature, humidity and amount of ventilation during storage and (5) length of storage. Smith (1933) found that potatoes harvested immature lost 9.89 per cent in weight during seven months' storage, whereas potatoes harvested when mature lost 6.97 per cent during the same period. Potatoes handled carefully during harvesting and storage lost 6.78 per cent during seven months' storage; those harvested in the normal manner lost 10.08 per cent. Potatoes which were cured for 8 to 12 days immediately after harvest under warm, moist storage conditions lost 7.54 per cent of their weight and those which were not cured had a weight loss of 9.33 per

cent during seven months' storage. At the end of one month storage, mature potatoes lost 4.66 per cent in weight; 6.41 per cent after three months; 7.74 per cent after six months and 8.91 per cent at the end of seven months.

Effect of Irridation on Stored Potatoes

Weight loss of Russet Burbank tubers decreases with increased dosages up to 15,000 to 25,000 REP, whereas the reverse is true with Sebago tubers (Brownell *et al.* 1957). Periderm formation is completely inhibited and suberization of cut areas is delayed at all levels of gamma irradiation from 15 to 200 kilo-REP. Consequently most storage rots increase with higher radiation dosages (Brownell *et al.* 1957).

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Clive M. McCay

The Nutritive Value of Potatoes

The appreciation of the food value of the potato is lost in the unrecorded history of South America. Europeans came to realize its great value about two centuries ago. Late in the 19th century Count Rumford taught the peasant soldiers of Bavaria to grow the potato in order that the people might improve their diets with it.

About the year 1795 Count Rumford wrote "With regard to potatoes they are now so generally known and their usefulness is so universally acknowledged, that it would be a waste of time to attempt to recommend them. Though there is no article used as food of which a greater variety of well-tasted and wholesome dishes may be prepared than of potatoes, yet it seems to be the unanimous opinion of those who are most acquainted with these useful vegetables that the best way of cooking them is to boil them simply, and with their skins on, in water" (Anon. 1875).

A hundred years later Snyder *et al.* (1897) wrote "In order to obtain the highest food value, potatoes should not be peeled before cooking. When potatoes are peeled before cooking the least loss is sustained by putting them directly into hot water and boiling as rapidly as possible." About this date we can learn about teachings of nutritionists by reading an "exercise" of one of the little girls in the cooking class of a New York school. She wrote "The people of Ireland use the potato as one of the chief articles of diet. But they drink large quantities of buttermilk or skimmed milk which contains a great deal of flesh forming material" (Hogan 1899).

When Grubb and Guilford (1912) published their book on the potato they quoted Dr. Kellogg of the Battle Creek Sanitarium who had written "The belief is quite general that the potato especially promotes fat making and hence that its use must be avoided, by persons who have a tendency to obesity. All foods tend to produce obesity when taken in excessive quantity. Potato gruel made from specially prepared potato meal or the pulp of baked potatoes has been found in Germany of very great service in the feeding of infants or invalids. If the consumption of potatoes in this country could be quadrupled, the result would undoubtedly be the saving of many thousands of lives annually and an incalculable amount of suffering from disease."

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The possible truth of these statements of Kellogg seem to have justification as one examines modern research.

Foods of unique nutritive value that are commonplace in ordinary times become much appreciated in periods of calamity such as war. The potato is the best modern example of such a food. During the American war between the states, scurvy took its toll in those prisons that could not get potatoes. Scurvy was almost unknown when potatoes were available.

A whole chapter was devoted to the importance of the potato in war time by Salaman (1949). War seems to have played an important part in introducing potatoes into France because Parmentier became a prisoner of the Prussians during the Seven Years War (1756–63). He believed his survival was due to the potato. From 1778 potatoes played an important role in warfare in England, Ireland and continental Europe.

Potatoes are among the most reliable foods to insure man's survival during modern wars. This has been amply proved during the last two world wars. Potatoes are not easily destroyed by fire even in storage because they contain enough water to prevent them from burning. Potatoes in the field cannot be readily burned in contrast to grain crops such as wheat. This was well illustrated after the fighting had swept over Okinawa. The people could dig potatoes and survive after most other food supplies were eaten or destroyed.

Potatoes also play an important role in war time because their production can be greatly expanded in home gardens when supplies of sugar or wheat are cut off for small nations like Switzerland. Unfortunately, man has not learned the great value of potato flour as a product to store along with wheat for periods of emergency.

The war-time experiences of nations such as Switzerland in which the use of potatoes increased while that of sugar declined provides evidence that potatoes may play a role in human well being that is little appreciated today. Under these war time conditions the decay of teeth decreased very much in nations such as Switzerland and Norway. The physical composition of potatoes probably plays a role in this preservation of teeth. Potatoes do not stick to the teeth like products that contain sugar. While it is well known that sugar promotes the decay of teeth even in solution, it is also well established that sticky candies increase the decay of teeth in children.

Improvement of teeth during periods of high potato consumption may be due to this lack of stickiness on the part of potatoes as well as the cleansing effect of the fiber in the skins of potatoes when these are eaten. Fleisch (1947) reported in a typical Swiss city such as Basel, potato consumption was 172 grams per person per day in 1936, and 415 grams daily in 1944. During this period according to Roos (1950), sugar consumption

dropped to about one half of the pre-war figure while the decay of childrens's teeth declined about 20 per cent.

Even in normal times the possible relation between the excellent teeth of the people in Tristan Da Cunha and their diet of potatoes has been discussed by Salaman (1949).

During the World War II period there were other changes of lesser extent in the Swiss diet such as increased consumption of beans and a decrease in the eating of pastries. Therefore, one can never fix the responsibility for the improvement of teeth upon a single foodstuff but must ultimately revert to animal research to test human observations.

Another advantage of potatoes during periods of stress is that they can be kept under relatively crude storage conditions. Mice and rats will eat them only if other foods fail. This neglect of raw potatoes by animals is well known to those who camp in the northwoods. Potatoes can be left on the trails and will usually remain untouched even by bears and chipmunks.

Average values to remember for the chief components of potatoes are protein 2 per cent, fat 0.1 per cent and carbohydrates 20 per cent. These values, however, lead many people astray in thinking about the value of potatoes for such nutrients as protein. Thus, one may see beside such values for potatoes, an average of seven per cent for the protein of rice. The analysis for rice is given on a nearly dry basis and the potato value for the fresh product that contains about 80 per cent water. For a truer comparison one should multiply the values for potatoes by five. This gives a value of ten per cent for the protein. If the quality of the protein is equally good this explains why millions of men can live on a diet comprised mostly of rice and others thrive equally well or better upon a diet rich in potatoes. This matter of expressing chemical values on a moist or dry basis is well known to food chemists but poorly understood by many others.

Food tables are very useful to everyone trying to compare values for different foodstuffs. Many of these have been assembled during the past century. For international use one of the best is that of FAO, by Chatfield (1949) while that of Watt and Merrill (1951) is useful and inexpensive for home use (Table 20).

In the last column of Table 20 is given a rough approximation of what a well fed man may need. With the exception of the value for energy most of the men of the world get about one-third or one-half of the vitamins and minerals shown here.

This table shows why milk is such a good supplement to potatoes or almost any other food. Milk supplies what the potato lacks in such elements as calcium. On the other hand potatoes have trace elements like

iron and milk does not. Potatoes have 0.17 mg. of copper per 100 gm. while milk is lacking in this element.

Fortunately for those who attempt to reduce their blood pressure by limiting their intake of salt, potatoes are very low in this substance. Raw potatoes have about 20 mg. per 100 gm. If potatoes are boiled in salt water with the peelings left on they do not take up any salt but if they are peeled they may increase the salt content by fifteen times. Therefore, potatoes should be peeled after cooking for those eating little salt.

Table 20

FOOD VALUES FOR POTATOES[1]

	Baked, 1 Medium	Boiled, 1 Medium	French Fried, 8 Pieces	Chips, 10 Pieces	Man Needs
Water, per cent	74	78	20	3	2 qts.
Energy, calories	95	120	155	110	2400
Protein, gm.	2	3	2	1	70
Fat, gm.	Trace	Trace	8	7	...
Carbohydrates, gm.	22	27	21	10	...
Calcium, mg.	13	16	12	6	800
Iron, mg.	0.8	1	0.8	0.4	12
Vitamin A, I.U.	20	30	20	10	5000
Thiamin, mg.	0.11	0.14	0.07	0.04	1.2
Riboflavin, mg.	0.05	0.06	0.04	0.02	1.8
Niacin, mg.	1.4	1.6	1.3	0.6	12
Ascorbic acid, mg.	17	22	11	2	75

[1] From U. S. Dept. Agr. AIB-*36*.

One unfortunate situation of the potato is that it may be damned by its associated foods. Since potatoes are low in salt but high in potassium, the custom of salting potatoes heavily when they are eaten has persisted. Salting most foods is a matter of habit and developed tastes. Potatoes are just as well liked if not salted after one adjusts himself to the changed taste. Potatoes and fat have also been long associated. Our childhood memories contain baked potatoes with a huge chunk of melting butter or a lavish coating of gravy over the potato. The individual who wishes to reduce his energy intake will find potatoes very delicious with the addition of little fat.

This association of potatoes and fat or gravy has given the potato a bad reputation for those who desire to remain thin. Few people can eat enough potatoes alone to make them fat. In nations that depend upon potatoes as a major source of energy such as Ireland and the Ukraine, the stomach must be stretched early by eating much of this bulky food in order that 5 to 10 lbs. of potatoes can be eaten daily by a working man at a later date.

In the light of both old and modern nutrition one of the best supple-

ments for potatoes is skim milk or buttermilk. These require some adjustment of tastes but these milk products yield a diet that is nearly complete except that it lacks vitamins A and D.

INORGANIC ELEMENTS IN POTATOES

More than 60 years ago, European workers such as von Bunge recognized that potatoes were among the richest foods in potassium and among the poorest in sodium. He believed that potato eaters had to salt potatoes because the rich potassium diet caused the kidneys to excrete excess salt and thus deplete the blood of sodium. However, he also believed that most people put too much salt on their potatoes and that this led to undue work for the kidneys.

Foods have long been studied in relation to their acidity or alkalinity when burned in the body. If a food such as meat contains an excess of sulfur and phosphorus these are oxidized to acids and the food has an acid ash. If a food such as potatoes is burned it ends as an alkaline ash because it has an excess of alkaline constituents such as potassium.

TABLE 21

THE INORGANIC CONSTITUENTS[1] OF POTATOES
(EXTREMES OF AVERAGES)

	Mg. per 100 Gm.		Mg. per 100 Gm.
P	166–314	Boron	4.5–8.6
Ca	32–88	Si	5.1–17.3
Mg	65–136	Mn	0.6–8.5
Na	26–332	F	0.6–8.5
K	1811–2430	I	0.02–0.56
Fe	2.6–10.5	Li	Trace
S	109–213	Al	2.9–8.8
Cl	112–530	As	0.3
Zn	1.7–2.2	Mo	0.26
Br	4.8–8.5	Co	0.26
Cu	0.4–1.0	Ni	0.26

[1] Lampitt and Goldenberg (1940).

Potatoes, beans and carrots are among the alkaline foods while meat, eggs, rice and bread are among the acid ones unless the bread is made with large amounts of potatoes or milk.

One of the best summaries of modern times concerning the composition of potatoes is that of Lampitt and Goldenberg (1940). In their data they assembled the extremes in average values found by different workers (Table 21). These values provide the nutrition student with information that can help in evaluating the part the potato plays in contributing various elements to the diet.

The human diet is seldom lacking in phosphorus so one seldom pays attention to this element unless it occurs in the form of phytin and in a

food low in calcium, such as wheat. Less than one-fifth of the phosphorus of the potato is in the form of phytin. No one has found that this interferes with calcium assimilation.

In vegetarian diets or diets low in calcium the potato has this asset of being very low in phytin which the chemist knows as calcium magnesium inositol hexaphosphate. Phytin is found mostly in cereal grains. In the process of milling it is discarded and hence tends to be low in white flour. Phytin has special interest when diets are low in calcium, because it tends to tie up and waste the calcium in the diet through excretion.

In a study carried out during the whole life span of the common test animal, the albino rat, Bharucha and McCay (1954) found that calcium in the form of gypsum served the animal very well at the low level of 0.3 per cent calcium if 69 per cent of the diet were made of potato flour. However, the animals did not thrive so well if the potato flour were replaced by whole wheat flour unless the calcium in the diet was increased to 0.6 per cent. In these studies the length of life of the test animals was the same whether the diets contained potatoes or whole wheat flour as the chief source of calories. The appearance of the animals which is usually judged by the fur coat seemed quite superior in those fed large amounts of potatoes.

This whole question of the unfavorable effects of phytin when diets of whole grains are eaten is still debated because it seems that those who become accustomed to diets rich in whole grains develop an ability to digest some of the phytin and hence do not suffer much loss of calcium even when the diet is low in this element (Irving 1957).

Rats in old age according to the findings of Bharucha and McCay had the best concentration of calcium per unit volume of bone when the animals had been fed the potato-rich diet for the whole of life. The bones of the poorest rats were those that had been fed a diet rich in white refined flour supplemented with calcium phytate. Animals fed the whole wheat flour were intermediate when judged by the quality of their bones in old age.

Since the loss of strength of bones is one of the greatest sources of suffering in the old age of man, any nutritional factors that will tend to ameliorate this are very important. Much more attention should be given to the influence of foods such as potatoes in relation to other components of the diet.

During the past five years a long time study has been completed in the Animal Nutrition Laboratory at Cornell University in which white rats were fed for the whole of life a diet comparable to that eaten by about one-third of the population of this country. In this study about three-fourths of the calories of the diet were provided by either breads

or potatoes. Two different kinds of bread were fed, one a typical oven bread consisting mostly of flour and water. The other was the highly supplemented bread of flour, soy flour, dry skim milk and wheat germ. The potatoes were fed as potato flour.

These rats were studied throughout the whole of life. From early in life the rats fed the oven bread were inferior in growth rate and health. A substantial number tended to die prematurely. The rats fed the special bread or the potatoes thrived throughout the whole life span. These rats lived much longer than those given the oven bread. In the end the rats fed the diets rich in potatoes had the best survival in old age and the greatest mean span of life.

Insofar as one is justified in carrying over the results of such tests into human application, it would seem that man is better off to base his diet upon potatoes rather than upon inferior bread if the basal diet of human foods is marginal. Potatoes seem equal or superior to the best bread we can make.

This study also indicated that the quality of the bones of the rats in old age was superior if they had been fed either the potatoes or the better of the two breads. Hence, it seems that man has some power to predetermine the quality of his skeleton in old age.

In the past, magnesium has been given little attention in human nutrition but it may become more important in the future since animal research indicates it may influence the formation of calculi in the bladder and the calcification of the soft tissues of the kidneys. A typical person excretes about a fifth of a gram of magnesium per day. This would be provided by about a half pound of potatoes if the remainder of the diet were low in this element. The human diets low in magnesium are those based largely upon milk or milk products because milk has only 12 mg. per 100 ml. (Halden 1956). It has only one-fifth to one-tenth as much magnesium as potatoes. Hence, milk and potatoes are excellent supplements since milk provides calcium and potatoes provide magnesium.

Since potatoes provide a good source of iron, some attention has been given to cooking losses. Pfund and Nutting (1942) found only about ten per cent loss in various forms of cookery. Salt in the water had no effect upon this loss. They found a substantial amount of iron in the peeling of baked potatoes. Fertilizers did not affect the iron content of potatoes according to the studies of Leichsenring and Donelson (1943). By paring they found a loss of 24 and 10 per cent, respectively, in the calcium and iron.

The iodine content of potatoes varies widely but cannot be correlated with the incidence of goiter according to the studies of Frear (1934) in Pennsylvania.

The potato does not accumulate the element selenium even in soils rich in this substance. Potatoes had only 0.1 p.p.m. in an area where the wheat contained 2 p.p.m. and a collecting plant such as *Astragalus bisulcatus* contained 1,000 p.p.m. (Trelease and Beath 1949). In human nutrition the trace of selenium needed is provided by wheat and other foods. In fact, there is more danger from too much rather than too little due to the mixing of wheats from soils rich in selenium. Little attention has been given to either human needs for selenium or human injury from too much.

The potato provides most of the trace elements that are lacking in milk such as iron, copper, manganese and iodine.

THE CARBOHYDRATES OF POTATOES

The starch in potatoes varies from 9.9 to 23.3 per cent according to the summaries of Lampitt and Goldenberg (1940). This starch is well utilized by men, swine, dogs and other animals after cooking. Sheep and cattle can be fed uncooked potatoes since they seem to utilize the raw starch. The starch of most grains can be eaten by men in moderate amounts without difficulty and some people live entirely upon raw foods. However, raw potato starch seems to have a special property of producing stomach cramps. Small amounts of raw potatoes can be eaten with pleasure if they are well chewed but we have found no evidence in the literature nor heard of any enthusiast who derived much of his energy needs from raw potato starch.

Many years ago Ivy *et al.* (1936) fed medical students different forms of raw starch. This was incorporated into ice cream. The experiment had to stop with raw potato starch because of the violent cramps produced. Potato starch when fed raw also caused trouble in three-day balance trials upon young women made by Langworthy and Merrill (1924). In similar studies by Fofanow (1911) it was also found that the utilization of raw potato starch was poor in comparison with that from wheat, oats and rice. Even some herbivora such as guinea pigs do not make good use of raw starch (Pozerski 1934).

In a mixed meal that contains substantial amounts of mashed potatoes, the starch of the potatoes is digested by the amylase of the saliva while the potatoes are in the stomach but before the stomach becomes acid from the gastric juice (Ivy *et al.* 1936).

Old traditions have often made the public believe that some starches are easier to digest and hence more appropriate for feeding invalids. Tapioca has long been such a favored food. There is no evidence whatsoever that potatoes are inferior in this respect. Cooked starches are digested and absorbed at about equal rates. At times sugars such as

glucose are advocated because they are absorbed into the blood more readily than starch. This is occasionally desirable but usually has no advantage. In fact, the body converts starch to glucose and feeds it steadily to the tissues as they need it in most cases.

Potatoes may have from 0.2 to 6.8 per cent sugars. A high sugar content gives cooked potatoes a "sickly sweet" flavor and may lead to their rejection as food especially in large scale feeding operations such as that in the Navy. This sugar can be reduced by storage of potatoes for one or two weeks in a room of moderate temperature. Such potatoes are then usable. In a Navy ship such potatoes are taken from cold storage and stored at room temperature.

In many vegetables this high sugar content adds attractive flavor. From $^1/_5$ to $^1/_3$ of the dry matter of cabbage, carrots, eggplant, lettuce, peppers, radishes, snap beans, squash and turnips may consist of soluble sugars without prejudicing the taste appeal (Bennett 1944). This is not true for potatoes.

Potatoes may have small amounts of some of the common organic acids such as malic, oxalic and citric. They may contain as much as one-half per cent of citric acid. However, at present these acids may modify flavor but have no relation to nutritive value.

Unfortunately, potatoes are often excluded from the diets of those who wish to reduce body weight. This is unfortunate because potatoes contain so much water and have such a satiety value that it is nearly impossible for anyone in America to eat enough of them to even maintain his body weight. The condemnation of the potato results from the butter, cream and gravies that provide much fat and are traditionally eaten with potatoes. Potatoes are a very pleasing food when eaten with no additives after boiling or baking. The old method of cooking advocated by Count Rumford in the days of George Washington is probably still the best. The boiling of the potatoes is started in cold water. After they are soft the water is poured off and the potatoes allowed to dry out somewhat over a warm burner.

The great advantage of the potato in the diet of all people is that it is one of the few foods that can be bought as it comes out of the ground. The vitamins and part of the minerals have usually been milled out of white flour; the germ has usually been taken out of corn meal; rice has usually been milled to make it white. However, potatoes are usually sold as produced.

THE PROTEIN AND NITROGEN COMPOUNDS OF POTATOES

For nearly a century scientists have been perplexed by the riddle of the potato in regard to its ability to provide growing animals or adults

with nearly enough of the right kind of nitrogen-containing compounds to satisfy basic needs. In this respect potatoes seem slightly better than whole wheat (Chick and Cutting 1943). The reason for this riddle is that only about half of the nitrogen in the potato occurs in the form of protein. Chick and Cutting state that 28 to 51 per cent of the nitrogen of the potato occurs in the form of protein.

The question of the maintenance of nitrogen balance upon a diet of potatoes and fat was given much attention by Hindhede. He claimed that a man was kept in equilibrium for more than three months upon potatoes although the protein intake was 11–15 gm. daily. Hindhede had grown up in an area of Denmark in which potatoes were the chief food of the people. His lifetime enthusiasm never failed.

TABLE 22

ESSENTIAL AMINO ACIDS IN POTATO PROTEIN AND IN THE NON-PROTEIN FRACTION[1] (EXPRESSED IN GM. PER 16 GM. OF NITROGEN WHICH IS ESSENTIALLY THE PER CENT OF THE AMINO ACID IN THE PROTEIN)

	Tuberin (1)	N.P.N. (2)	Mixture 53 pts. (1) plus 47 pts. (2)
Phenylalanine	6.6	4.1	5.4
Leucine	17.5	4.3	11.3
Valine	6.1	3.3	4.8
Tryptophan	1.6	...	0.8
Threonine	6.0	2.6	4.4
Arginine	2.2	1.1	1.7
Histidine	7.7	1.9	5.0
Lysine	2.1	1.2	1.6
Methionine	2.3	0.8	1.6

[1] From Chick and Slack (1949).

German workers (Salaman 1949) claimed that a man could not maintain nitrogen balance if the only source of protein was potatoes. While they found that 95 per cent of the nutrients of the potato were absorbed and utilized by the body they found that about 30 per cent of the protein was not well utilized. This was probably not true protein but nitrogenous compounds.

Chick and Slack (1949) determined the content of the essential amino acids in the protein of potatoes which is commonly called "tuberin" and in the form of free compounds that are water soluble. Their data are given in Table 22. At the end of their study they were still mystified as Rubner had been seventy years earlier that potatoes were such a good source of protein. Those who believe that chemical fragmentation will ultimately provide all the answers in the field of nutrition will be sur-

prised by their conclusion "The potato tuber is a living, changing system and the processes involved in the separation of its constituents, no matter how carefully operated, seem to bring about unknown changes detrimental to nutritive value."

In a summary table of true and crude protein by Lang (1957) he summarized the variations in content of true protein in various plant foods. In hazelnuts with more than three per cent of the dry matter as nitrogen he noted that this is 96 per cent true protein while the lowest is that in red beets which contain 1.16 per cent of nitrogen and only 41 per cent of this is in the form of true protein.

TABLE 23

AMINO ACID CONTENT OF POTATOES[1]

	Boiled	Chips	French Fried	Mashed	White Bread
	Mg. per 100 Gm.				
Isoleucine	0.89	3.46	2.89	1.21	5.51
Leucine	1.09	4.21	2.25	1.54	7.94
Lysine	1.10	3.66	2.03	1.31	2.54
Methionine	0.26	0.92	0.47	0.35	1.62
Phenylalanine	0.86	2.79	1.57	1.04	5.29
Threonine	0.76	2.48	1.47	1.02	3.32
Tryptophan	0.24	0.57	0.45	0.22	0.89
Valine	1.19	4.22	2.48	1.25	5.46

[1] From Wertz *et al.* (1956).

The limiting essential amino acids in potatoes according to Lang (1957) are methionine and cystine. The same two are given in reverse order for milk. Nevertheless potatoes and milk are good supplements. Less strange is the supplementary values of cereal proteins such as those in wheat and potatoes. Cereals are usually deficient in lysine. The old prejudice of the housewife against serving potatoes and bread at the same meal would not seem justified. However, the prejudices of the housewife have never been too marked in the potato eating areas of America since bread, butter and potatoes were considered a satisfactory meal.

The content of cooked potatoes in essential amino acids has been determined by Wertz *et al.* (1956), Table 23. In the study of data in such tables one needs to be sure that he thinks in terms of foods with equal amounts of water or solids. Since boiled potatoes are about four-fifths water when eaten after boiling and bread is only one-third water one can compare them on a dry basis by multiplying the boiled potato values by five and increasing the values for bread by 50 per cent to put both products on a comparable dry basis. In the case of chips there is little mois-

ture and one needs merely to convert the bread to a dry basis for rough but adequate comparisons.

It has been suggested that some compound of the potato such as glutamine may have a substantial influence upon the efficiency of the utilization of the nitrogen. It is well known that certain amino acids act as antagonists to each other. If there are compounds in the potato that prevent this antagonism and afford efficient use of protein, these compounds may ultimately have a profound influence upon human destiny since it is commonly realized that protein deficiency is one of the world's major problems.

In addition to amino acids many other nitrogen-containing compounds have been isolated from potatoes. A few of them are solanine, xanthine, trigonelline, hypoxanthine, adenine, cadaverine, guanine, narcotine and acetyl choline. These are not considered important in nutrition but solanine has long been of interest because it tends to have an increased concentration in potato sprouts and in potatoes that have turned green when exposed to light.

Solanine was discovered in 1820 and found to be related to atropine and nicotine. About 1826 it was found to be rich in sprouts. Since sprouts are seldom eaten and since they have a very bitter taste, few people have even been made sick by solanine. Hence, the problem is academic but has some interest.

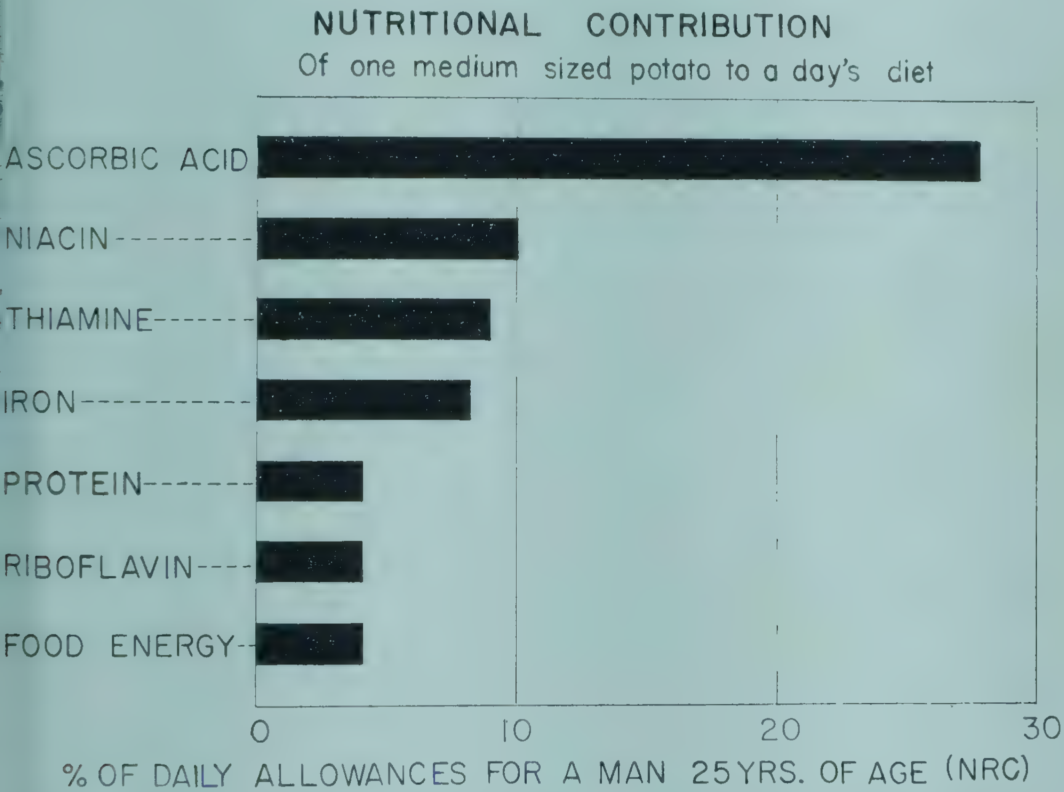
About 100 mg. of solanine will produce nausea, headache and gastrointestinal pains in a man. Some cases of such symptoms have been recognized in the German army when men have eaten potatoes containing 20 to 60 mg. percent of solanine. If such men ate a pound of potatoes they would get at least the 100 mg. (Zettel 1937).

Zettel cites a case in Germany where potatoes were stored in two bins in a cellar. One bin was dark and one had a source of light. People were made sick by the potatoes stored in the bin exposed to light but not by those kept in the dark. In America potatoes are always stored in the dark except in some homes. The only question of interest to most Americans is that regarding the occasional potato that is partly green. No evidence indicates that such potatoes are harmful. The reason seems to be that part of the solanine is rendered harmless by cooking and the total amount eaten is not great enough to produce nausea.

Numerous tests have been made in feeding solanine to test animals. Mice seem quite sensitive to this compound while swine are little affected by it. The compound is interesting to the scientist but has little of practical importance. It may exist in the sprout as a repellant against the enemies of the potato during the early growth period and hence might have some merit as a garden spray material.

VITAMINS IN POTATOES

Before the modern era of abundant citrus fruits in Europe and America, the chief foods that protected man against scurvy were cabbage, potatoes, tomatoes and fruits such as apples. Until the time of the Revolutionary War more than a century and a half ago, many people suffered from mild scurvy because they had only cabbage and apples during much of the winter season to protect them. Raw milk and meats provided some vitamin C but men drank little raw milk and usually fed the most nutritious meat, namely the liver to the dogs and cats.



From U.S. Dept. Agr. Bull. 178

FIG. 43. NUTRITIONAL CONTRIBUTION OF ONE MEDIUM-SIZED POTATO TO A DAY'S DIET

The widespread cultivation first of potatoes and later tomatoes gave man two of his best protective foods. Raw potatoes were so highly valued in the America of our great grandfather's day that whaling ships used to preserve them for long voyages by covering them in casks with molasses. Potatoes were also preserved in vinegar.

Fortunately for man, potatoes can be stored for the whole winter season. Until modern times, man approached closer and closer to scurvy as the winter progressed. Unfortunately, the potato loses some of its vitamin C but retains substantial amounts until it sprouts in the spring. The

amount even increases slightly during the sprouting as it does in the case of sprouting seeds. Potatoes saved our ancestors from scurvy until they could gather some wild plants and begin to eat rhubarb in the spring.

The chart (Fig. 43) from the bulletin on potatoes by Fincher and Mountjoy (1957) illustrates the contribution of a medium sized potato. When it is realized that the National Research Council values are very liberal and that one may remain in good health upon half of values given for such components as protein and vitamin C, the value of the potato is quite evident and even impressive.

When one appreciates that there are three medium sized potatoes in a pound and that men whose diet is composed largely of potatoes may eat 5 or 6 pounds daily, it is easy to understand why nutritional diseases are not associated with potato eating areas. This chart also illustrates the value of milk in supplementing potatoes since milk is rich in protein and riboflavin. Other natural foods such as brewers yeast should also provide an excellent supplement for these constituents but yeast lacks the calcium which is provided by milk products.

The vitamin C content of potatoes has been studied extensively and reported in numerous papers from various nations. A representative report such as that of Karikka *et al.* (1944) gives an adequate amount of information for nutritionists. In this study of eight varieties grown in various places with different conditions of fertilization they found mean values ranging from 9 to 33 mg. of ascorbic acid per 100 gm. of potatoes. Variables studied included pH of the soil, fertilization with numerous trace elements, growth in different counties and various soils. No relationship could be established between any of these numerous variables. One must conclude that there is a variation of about 300 per cent but that we do not understand what produces the differences. These authors found some relation to variety but even this has been denied by later workers. In one case the potatoes were fertilized with twelve tons of barnyard manure per acre; in another six minor elements were added. These were copper, zinc, boron, manganese, magnesium and iron. No relations were found to the vitamin C content.

In this study the decrease in ascorbic acid was from 26 mg. after harvest in October to 8 mg. per 100 gm. in May. The rate of decrease was somewhat more rapid for those stored at 40°F. than for those held at 50°F. When boiled such potatoes had 16 mg. of ascorbic acid when first harvested with a gradual decline to 5 mg. per 100 gm. in May. About ten per cent of this ascorbic acid could be recovered from the cooking water indicating the value of conservation of such fluids.

In a study of 20 varieties of potatoes by Allison and Driver (1953), the decrease in the course of eight months of storage was from 16 to 10 mg.

per 100 gm. of fresh potato. Therefore, a man who ate one-half pound of potatoes daily would have protection against scurvy, even at the end of the winter.

Some dehydrated potatoes are sulfited. This destroys thiamin but retains the niacin and ascorbic acid.

During World War II some studies were made of the losses of water soluble vitamins during the cookery of potatoes. At the Brooklyn Navy Yard, Heller *et al.* (1943) found that the raw potatoes in midwinter contained the following amounts of the water soluble vitamins per 100 gm.: thiamin, 53 to 90 gamma, riboflavin 30 and niacin 0.32 to 0.54 mg. The vitamin C in these potatoes was 8.7 to 15 mg. The cooked potatoes which had been steamed provided the following per serving of 112 gm.: thiamin 100 gamma, riboflavin 40 to 80 gamma and niacin 0.3 to 0.6 mg. The vitamin C in the helping of cooked potatoes was only 1.7 to 4.8 mg. These potatoes had been handled badly inasmuch as they were peeled a day in advance, soaked in water and the water discarded. The apparent increase in the thiamin value in cooking was due to the inadequacy of the analytical method for raw materials of plant origin.

An extensive study of large scale cookery of potatoes was reported by Streightoff *et al.* (1946). Their raw potatoes contained 16 to 27 mg. of ascorbic acid per 100 gm. Only five per cent of this was lost in steaming while 24 to 68 per cent was lost in mashed potatoes depending upon how long they were held after mashing. Baked potatoes lost 28 per cent of the ascorbic acid and boiled ones only 13 per cent. Earlier studies by various people had indicated that French-fried potatoes lost 16 to 35 per cent of the ascorbic acid while oven browned and hashed browned lost about two-thirds of the vitamin.

In the work of Streightoff *et al.* there was little loss of the niacin, thiamin or riboflavin when potatoes were mashed, boiled, steamed or baked. The greatest loss found was only 17 per cent. Their raw potatoes contained in terms of mg. per 100 gm. the following: niacin, 1.7–3.3, thiamin 0.08–0.13 and riboflavin 0.03.

Since potatoes are low in fat, little attention has been given to them as sources of the fat soluble vitamins. Some evidence has been found that potatoes increase the efficiency of the utilization of vitamin A in the animal body but this effect of potatoes upon the fat soluble vitamins has been given little study. While some plant products such as lettuce and wheat germ are good sources of vitamin E, no consideration has been given to potatoes.

Potatoes have not been considered as sources of the less common water soluble vitamins such as pyridoxine. However, no evidences of

human deficiencies in such factors are known for areas with people living largely upon potatoes. This does not indicate the adequacy of potatoes in such factors since little is known of the more subtle aspects of disease in relation to geography and in relation to food supplements that are commonly eaten along with potatoes.

NUTRITIVE VALUE AND PESTICIDE RESIDUES

Root crops such as potatoes are among the plant foods that are likely to carry the least amount of toxic residues. Foods that grow above the ground are subject to numerous enemies that are destroyed by spray materials. The potato plant is subject to similar hazards but the tops of white potatoes are not eaten. Unless a spray residue is applied to the soil or unless there is translocation of the residue from the green top to the tuber, the potato is not subject to suspicion. Some insecticides such as benzene hexachloride have been discarded because they created bad flavor.

Table 24

SPRAY RESIDUES

Name	Chemical Name	Tolerance Level in p.p.m.
Aldrin	Hexachlorodimethanonaphthalene	0.1
Chlordane	Octachlorohexahydromethanoindene	0.3
Heptachlor	Heptachlorotetrahydromethanoindene	0.1
SES	Sodium 2,4-dichlorophenoxyethylsulfate	6.0
Malathion	*O,o*-dimethyl dithiophosphate of diethyl mercapto succinate	8.0
Bromide	From methyl bromide	75.0
Maneb	Manganous ethylenebisdithiocarbamate	7.0

Spray materials are subject to rather rapid change in use so any tables of tolerances soon become outdated. However, a few tolerances for potatoes are included in Table 24.

Fortunately the skin of potatoes is not penetrated by such spray materials as DDT that may be used for fly control in places where potatoes are sold.

NUTRITIVE VALUE OF POTATO FLOUR AND BY-PRODUCTS

Although potato flour is used to a limited extent in the baking industry, it has not been used much in home cookery since it is not widely available in retail stores. Hence, it is a product somewhat foreign to the housewife but one that could be used. Potato flour has found some use in preparing special foods in mental hospitals for groups such as

the spastic feeble-minded (McCay 1956). It seems very useful in making mixtures of high nutritive value. In these cases it is easily prepared as a gruel with hot water or milk. Such gruels have special merit because they are slightly "sticky" and hence not easily rejected by those feeble-minded that must be fed regularly.

A dry mixture shown in per cent, that proved very satisfactory in feeding these feeble-minded consisted of potato flour from cooked potatoes 41, dry brewers' yeast 3, wheat germ 3, powdered skim milk 6, full fat soy flour 10, cooked cereal (corn flakes, shredded wheat or puffed rice) 10, powdered eggs 10.5, sugar 12, salt 2.5, alfalfa leaf meal 0.5, human grade bone meal 1.5 and irradiated yeast (one pound per ton of mixture). Strange as it may seem the flavor for such a mixture that appealed to children was banana. Possibly some banana flour should have been included.

The satiety value of potatoes and bananas is very high. This means that they give a feeling of fullness in the stomach. This is important in our modern age in which about 20 per cent of our people suffer many diseases from overweight. The Germans found many years ago that it took six pounds of potatoes per day to maintain a man with moderate exercise. Most people cannot eat this amount. If potatoes are eaten with very modest amounts of fat and salt they constitute an excellent reducing diet.

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W. O. Harrington

Preparation of Potatoes for Processing

Peeling is perhaps the most important of all the various unit operations undertaken in the processing of potatoes. Efficiency of peeling is not only necessary to minimize losses of raw material, but is the determining factor in fixing costs for subsequent inspection and trimming.

Under ideal conditions, peeling would require removal of only a very thin outer layer of the potato; it would leave no peel, eyes, or other material to be removed subsequently by hand trimming; and, above all, it would leave the newly exposed surface of the potato unchanged by contact with heat or chemicals. Unfortunately, in actual commercial operations, ideal conditions are never achieved. In several types of potato processing, inspection and trimming account for about one-half of the total labor costs. In some instances, peeling losses may run as high as 25 to 30 per cent. In still others, processors find that the peeling procedures they are using cause certain undesirable changes in the surface of the peeled potatoes.

No single method of peeling is universally applicable to and satisfactory for every situation. Size and nature of the enterprise must be taken into consideration in any decisions that are made in the choice of peeling equipment and procedures to be used. In most instances compromises in terms of yields, trimming costs and even in product quality may be necessary in order to achieve certain desired objectives.

The various considerations involved in choosing the correct method of peeling and a discussion of other closely related operations are given in detail below. It is assumed at this point that the proper raw material has been selected by the field men or purchasing agents and that it has been properly inspected and tested to see that it meets with specifications that have been decided upon for processing.

WASHING

Incoming potatoes are thoroughly washed in order to remove all sand and dirt (see also p. 256 and 355). This is quite important even though the potatoes are to be peeled later. Any sand or dirt that is

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carried over into the peeling equipment will erode the gasket material of the steam peeler, damage the pump of the lye peeler, or greatly reduce the service life of abrasive peelers.

In many large plants incoming potatoes are washed by the water in which they are transported from the storage rooms or receiving area into the processing plant. Fluming is an economical method of transporting potatoes from one point to another with a minimum amount of damage from bruising. During the several minutes that may be required to move the potatoes to the plant, much of the adhering dirt and mud is removed. Stones and gravel are frequently removed during fluming by increasing the depth of the water at one or more points to permit settling of the heavier stones and gravel. Potatoes are kept from settling in these stone traps by agitation of the water with compressed air or other means.

All incoming potatoes, except those that have been adequately washed by fluming or that were washed prior to purchase, are passed through washers. These provide means for scrubbing the surfaces of the potato with brushes or rubber rolls or for rubbing and rolling the potatoes in such a way that contact between the potatoes themselves loosens adhering dirt. Barrel-type washers are quite commonly used. In these, potatoes are tumbled and rubbed against each other and against the sides of the barrel while the potatoes are immersed in, or sprayed with water. Washers equipped with rotating brushes or ribbed rubber rolls are also used. Deep water washers may use revolving scrolls, paddles, or flowing water to move the potatoes forward. Washing also assists in sprout removal.

After leaving the washers, potatoes are permitted to drain for a short time during elevation or conveyance on metal mesh belts. They may then pass over a short inspection belt where trash, vines, and potatoes showing rot, greening or other objectionable defects are removed.

PEELING

As stated earlier, there is no one method for peeling potatoes that will satisfy the requirements of every type of plant (see also p. 215 and 256). For small plants, processing only a few thousands of pounds of potatoes per day, compact, inexpensive equipment that can be easily started or stopped by throwing a switch is most suitable. With this equipment, peeling losses and labor requirements for peeling and trimming are usually quite high. Other inherent advantages, such as flexibility of operation, at least partially offset the disadvantages.

Small plants are usually located near the area where their product is to be marketed, and in most instances at some distance from a major

potato producing area where suitable raw material can be obtained. Under these conditions, sized and graded potatoes, especially suited to the type of product being prepared, are normally used.

Large processing plants are usually located in or near a major potato producing area where an adequate supply of potatoes for processing is available for a major part of the year. In these plants continuous peeling equipment is normally favored over batch-type peelers even though the capital costs are higher for continuous peelers. Lower labor costs more than offset the higher capital charges.

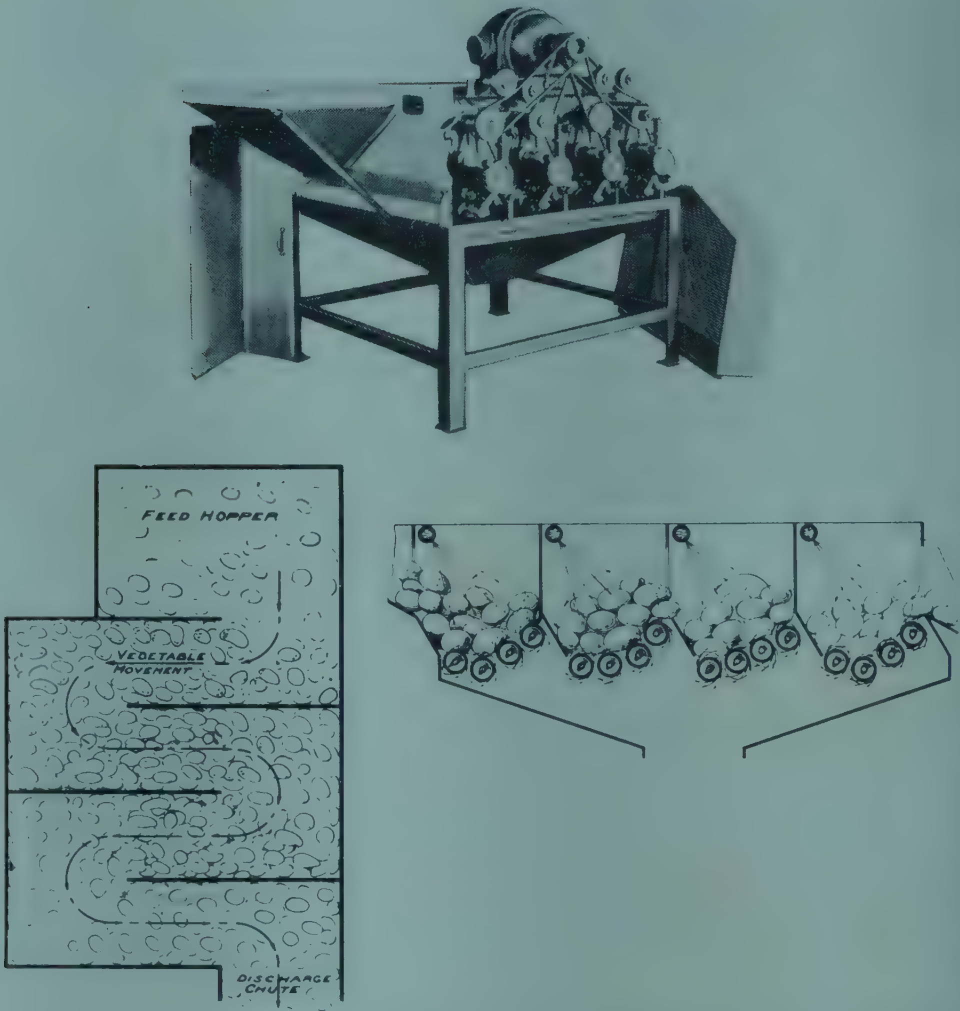
In processing large quantities of potatoes, peeling should be conducted in such a way as to minimize the amount of hand trimming and inspection required for the product. This is particularly true where the plants are located in major potato producing areas and using field run potatoes available at fairly low cost. Under these conditions, it may be more economical to peel a little more deeply thereby reducing trimming costs. In areas where raw material is more expensive, it may be more economical to use less efficient peeling and do more hand trimming.

Potatoes are peeled by the use of heat, chemicals, and abrasive action. Types of peelers that have been used to peel potatoes include abrasion, lye, steam, brine and flame peelers.

Abrasion Peeling

Abrasion peelers, whether batch-type or continuous, are theoretically designed to contact uniformly the surfaces of the potatoes being peeled with abrasive disks or rolls in such a way as to remove the peel with as little peeling loss as possible. Batch-type peelers usually consist of a vertical cylindrical container for holding the potatoes, with a rotating disk forming the bottom. Turning of the disk rotates the potatoes so that they contact the abrasive surfaces which may be on the disk or the sides or on both. Provision is made for discharging the peeled potatoes from the bottom of the peeler.

Continuous abrasion peelers vary in design as shown in Figs. 44 and 45 but basically they have the same elements found in the simple design of the batch-type peeler. The primary objective of all abrasion peelers is to insure the spinning or rotation of the potatoes being peeled so that all surfaces are equally exposed to the rasping action of the abrasive surface. Water sprays flush potato tissue from the abrasive surfaces and reduce the tendency of potatoes to darken through enzymatic action. How well this objective is achieved determines the effectiveness of the equipment under a given set of conditions. Shape of potatoes and the volume of potatoes greatly affect its efficiency.

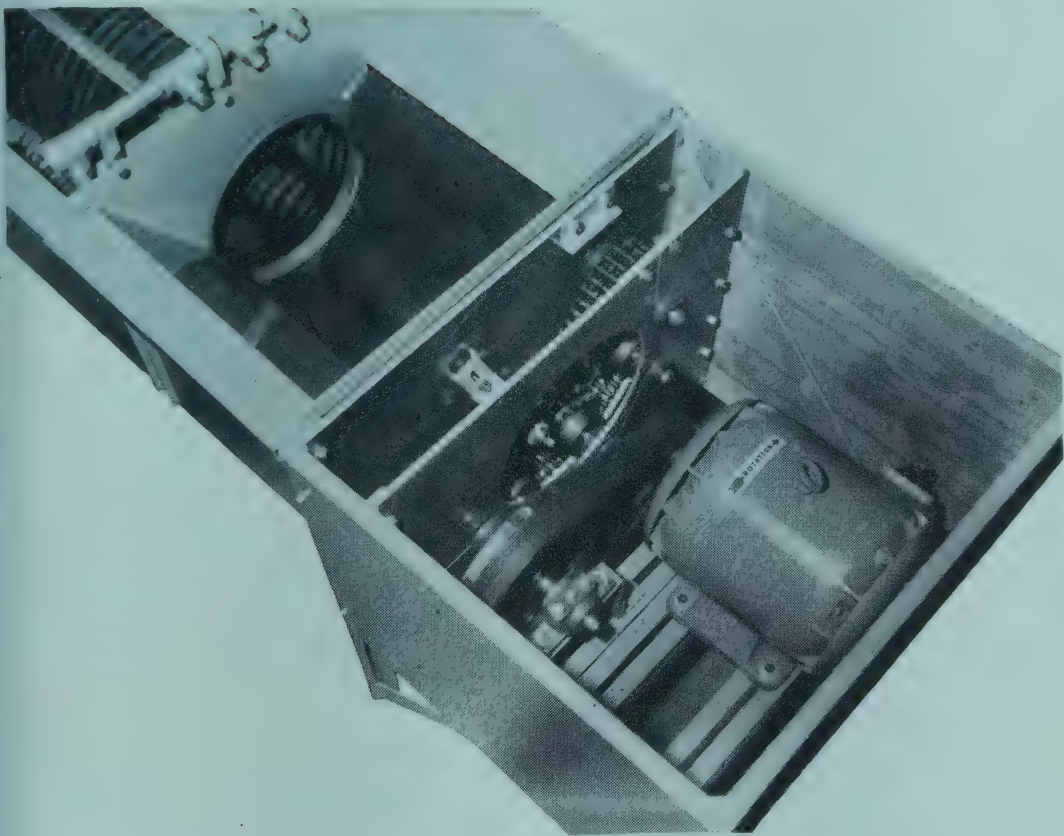


Courtesy of Food Machinery and Chemical Corporation

Fig. 44. Continuous Abrasion Peeler, Roller Type

Round potatoes are much more suitable for abrasive peeling than the long types; overloading abrasion peelers interferes with the normal path that the potatoes travel and results in less efficient peeling and greater peeling losses. Potatoes having digger cuts may skid on the flat surface rather than spin, thus losing excessive tissue on one side.

Non-uniformity in size has been observed to cause uneven peeling with most abrasive peelers. Greig (1956 and 1957) reported that peeling losses are greater for small than for large potatoes. Wright and Whiteman (1949) found that some varieties of potatoes can be abrasion peeled with less loss than other varieties. Varieties having deep set eyes are not suitable for abrasion peeling since additional trimming is required to remove the eyes remaining after peeling. Knobs on potatoes are either ground off or peel is left at the base.



Courtesy of Veg-A-Peel Co., Inc.

Fig. 45. Continuous Abrasion Peeler

One abrasion peeler has revolving rings (Fig. 45) to permit more effective contour peeling. In this peeler, potatoes are rotated in order to obtain proper alignment so that more uniform contact is made with the peeling surfaces. The surfaces of abrasive rolls in continuous peelers may vary in roughness. Rolls with finer abrasive surfaces are placed near the discharge end of the peeler in order to obtain a smoother surface on the peeled potato.

Although marked improvement has been made in abrasive peelers during the past few years, none has proved to be entirely satisfactory for all potatoes. Eye and stem removal still remains a problem with certain types of potatoes.

Abrasive peelers have been used in some plants to supplement lye peeling. In those instances, the abrasive peeler abrades any of the softened surface not removed by washing. Abrasion peelers are also used to reduce potatoes to the round uniform sizes needed for canning and to remove the cooked surface layer on lye- or steam-peeled potatoes which may interfere with the penetration of calcium chloride used to firm the canned product.

Greig (1956) reported the advantages of abrasive peelers to be their simplicity of operation, compactness of the unit, low cost of installation, and convenience of operation. Little extra equipment such as boilers and washers are required. The surfaces of potatoes peeled by abrasive peelers have not been altered by contact with high temperature. This is a decided advantage for certain types of processing, such as pre-peeling or potato chip manufacture, where the presence of a cooked layer of tissue—a heat ring—make the potato unsuitable for use.

In the preparation of certain products such as potato chips, complete removal of the skin is not necessary particularly when freshly harvested potatoes having thin skins are being used. Under these conditions, peeling losses and trimming labor requirements are greatly reduced. Smith (1957) estimated the peeling losses of the potato chip industry, which uses abrasion peeling extensively, to be about ten per cent. Peeling losses will be at a minimum with abrasive peelers when using large round potatoes having thin smooth skins and shallow eyes.

Lye Peeling

Lye peeling of potatoes combines the effect of chemical attack and thermal shock for loosening and softening the surface skin, blemishes, and eyes of the potatoes to the extent that they may be readily rubbed or worked off by pressure spray washers. Two general procedures for lye peeling are in general use. One method uses lye at temperatures considerably above the starch gelation point of about 160°F. In the other, low-temperature lye peeling, caustic solution ranging from 120° to 160°F. is used. Low temperature lye peeling depends on chemical decomposition, hydration, and softening of the skin and surface components of the potato using temperatures that do not result in cooking or denaturing of the underlying potato flesh. The objective obtained in low temperature lye peeling is the reduction or elimination of the cooked, denatured, surface layer or heat ring on the peeled potato (Olson and Treadway 1952).

Both low- and high-temperature lye peeling use similar equipment. Normally longer contact time with the lye solution will be required when low temperatures are used. Longer contact times make possible more precise control of the process. With low temperatures, it is necessary to have more rapid and uniform circulation of the lye solution through the mass of potatoes being peeled. The greater viscosity of the lye solution at low temperatures increases the need for rapid circulation. Starch, protein and other components that are dissolved in the lye solution further increase its viscosity.

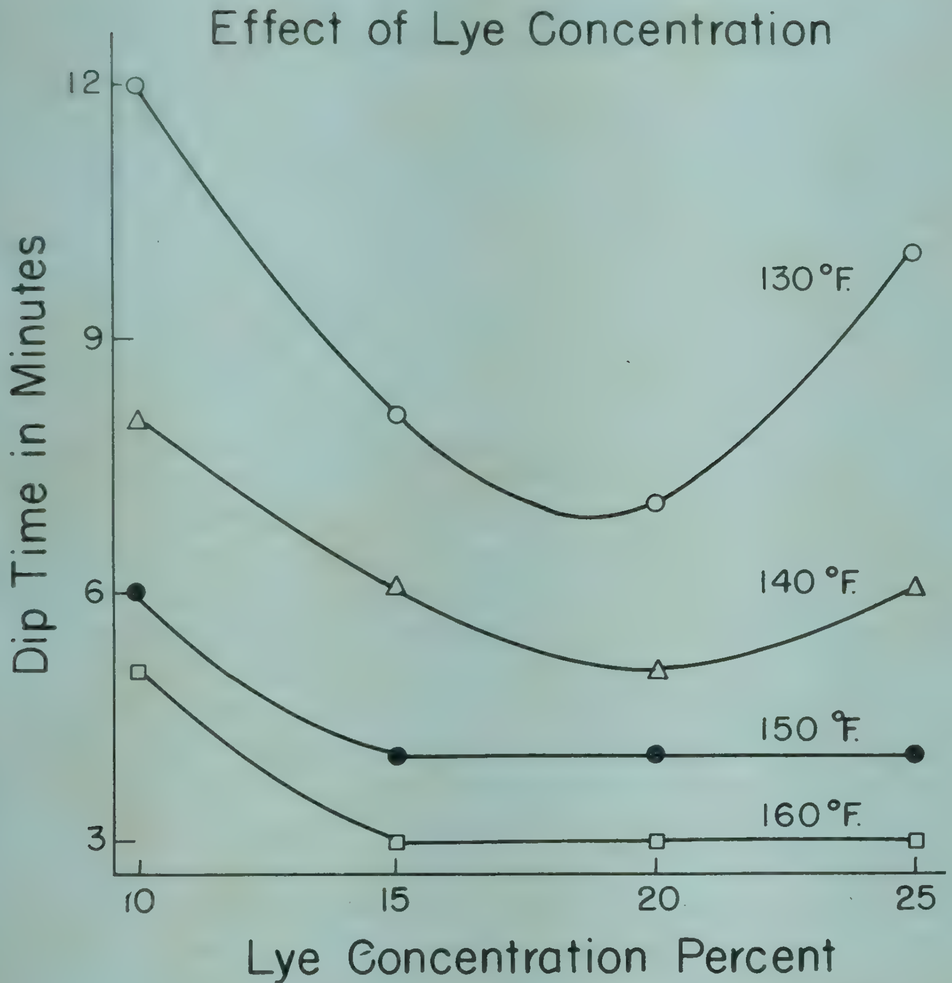


FIG. 46. EFFECT OF LYE CONCENTRATIONS AT LOW TEMPERATURES ON PEELING

The interrelationship of immersion time, lye concentration and temperature are shown in Fig. 46. With temperatures below 140°F., minimum peeling times are obtained using lye concentrations of 15 to 20 per cent. The increase in required immersion time with lye concentrations above 20 per cent is perhaps due to increased viscosity of the lye solution which makes it more difficult to obtain adequate circulation of the peeling medium. These results were obtained with U. S. No. 1 Russet Burbank potatoes having a minimum of growth cracks and other defects. With a peeling loss of about nine per cent, adequate peel removal was obtained.

If a heat ring or partially cooked layer of tissue remains on the peeled surface, this can be removed by immersion in a second lye solution maintained at a still lower temperature (Harrington 1957). Temperatures of the second solution may be as low as 70°F. using lye concen-

trations ranging from 10 to 40 per cent. In this work it was found that a solution containing 15 to 20 per cent caustic maintained at 120°F. effectively removed any heat ring caused by high temperature lye peeling. Harrington also found that effective peeling with no residual cooked surface could be obtained by immersion for one minute in a 10 per cent lye solution maintained at 200°F. followed by immersion for two minutes in a 15 per cent lye solution at 120°F. When using unpeeled potatoes, lye baths below 100°F. are not effective in peel removal but, once the peel is softened by contacting with lye or steam at higher temperatures, the lower temperature solutions will complete peeling.

High temperature lye peeling is generally used by the larger potato processors (Jones 1953). This requires immersion of potatoes from 2 to 6 minutes in a solution containing 15 to 25 per cent lye maintained at 190° to 220°F. Optimum immersion times and peeling losses depend on variety and age of the potatoes being peeled as well as the concentration of caustic in the solution and its temperature. Caldwell *et al.* (1943) reported that differences between lots within a single variety may affect peeling characteristics to a greater extent than varietal differences. High temperature lye peeling is much more effective in penetrating and removing heavily blemished or diseased areas than is low temperature peeling.

During lye peeling, the entire surface of the potato, regardless of shape or eye positioning, is affected and softened equally by the action of the lye. The surface assumes a deep yellow color due to reaction of the lye with the normal constituents of the potato. Lye penetration to a depth of one-sixteenth inch normally is adequate for efficient peeling. Rapid circulation of lye solution through the mass of potatoes is essential for uniform peeling whether low or high temperatures are being employed.

Sludge is formed in the peeler as a result of chemical action of lye on the potato tissue and subsequent loosening of this material as the potatoes pass through the peeler. This sludge is allowed to settle and is drawn off from the bottom of the peeler or lye storage tank or is removed by screens or other filtering devices. If the sludge is removed, the useful life of the lye solution is greatly extended.

The concentration of lye in the solution should be checked periodically by titration with standard acid solution using phenolphthalein as an indicator. Lye is added as needed to maintain the desired concentration. Experienced operators of lye peeling equipment are able to tell by the appearance of the potatoes as they emerge from the peeler and washer when caustic should be added. Records of one company

show that about 65 per cent of the caustic is actually used in peel removal. The balance is lost through mechanical entrainment, spilled or discarded during clean-up.

Lye is available to the processor in flake or cake form and as a 50 per cent solution. Flake caustic is more expensive than the cake form but is easier to use and requires less labor and equipment for handling. Liquid caustic is quite convenient to use but is the most expensive form and may not be generally available.

In many plants, potatoes are routinely preheated for a short time in water maintained at temperatures ranging from 140° to 190°F. Higher surface temperature, obtained by preheating, minimizes the cooling effect of the potatoes on the lye solution, aids in maintaining a uniform temperature throughout the solution and increases the capacity of the peeler. Only a fairly thin outer layer needs to be preheated in this fashion to accomplish the desired effects in lye peeling.

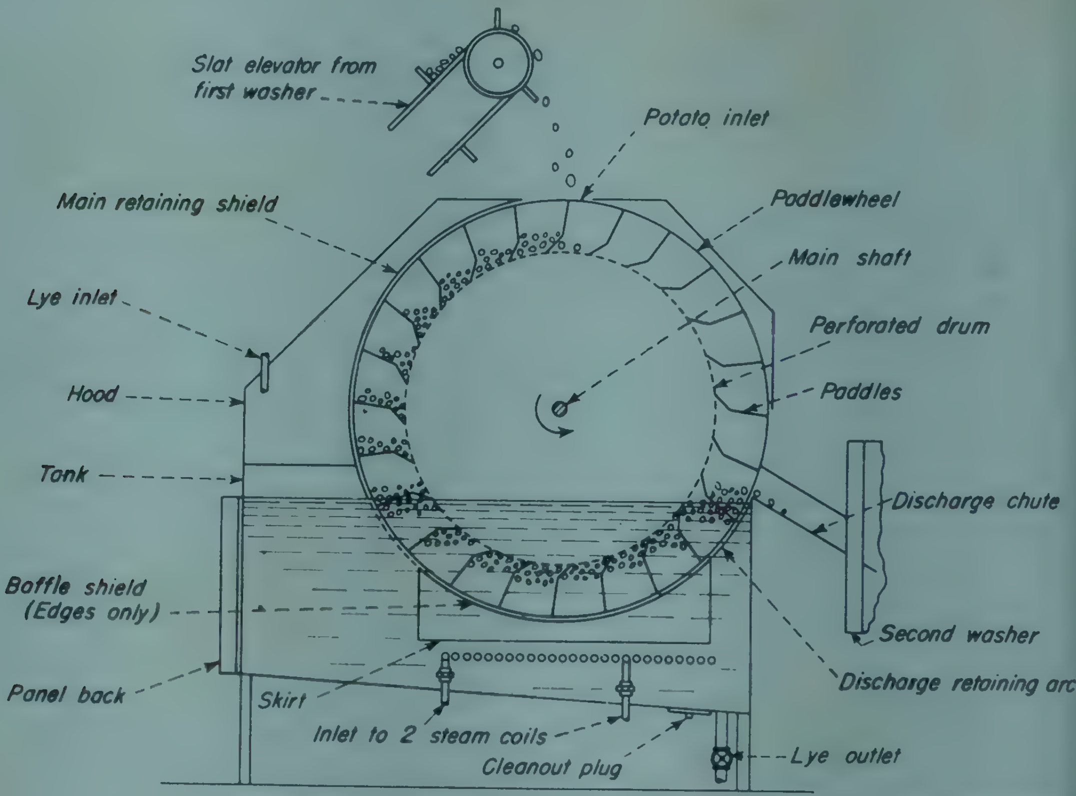
Some processors have added detergents or wetting agents to water used for washing or preheating potatoes. Lankler and Morgan (1944) and Olson (1941) reported that detergents improved lye peeling.

After emerging from the lye peeler, potatoes go directly to a washer. Roller, brush, or barrel type washers described above are generally used. If the lye-affected surface is not removed immediately by vigorous washing, it soon hardens and becomes much more difficult to remove. Unless lye is washed off or neutralized, it continues to react with potato tissue until spent. Any caustic not removed will result in a subsequent yellowing of the surface of the potato due to reaction with naturally occurring flavones in the potato. After washing, potatoes are sometimes sprayed or immersed in a dilute solution of sodium bisulfite or hydrochloric, citric, phosphoric or other acids. These will neutralize any residual caustic. Acid dips may be more economical in some instances than prolonged washing for removal of residual lye solution. Phenolphthalein turns pink when applied to the surface of a potato containing residual caustic and may be used in checking for completeness of lye removal.

Lye Peeling Equipment.—The draper, rotary screw and mill-wheel or reel-type lye peelers are used in potato processing plants. Each of these peelers is designed so as to submerge the potatoes in a heated lye solution and maintain them in this solution for a predetermined time. The draper belt is equipped with lugs or other means of conveying potatoes through the peeling medium. The helical screw lye peeler advances the potatoes through a hot lye bath by the rotation of a screw conveyor operating in the caustic solution.

The mill wheel-type lye peeler, designed by Thurber and Bohne (1946), is shown in Fig. 47. This peeler transports the potatoes

through the lye peeling solution as the wheel rotates, the lower portion of the wheel being in the lye solution. The potatoes are in effect carried through the hot lye as a succession of small batches held between flights on the periphery of the wheel. All points of friction on this peeler are free from contact with the lye solution. When properly constructed and operated, it performs excellently with a minimum of servicing.



Courtesy of Food Engineering

FIG. 47. CONSTRUCTION DIAGRAM OF A ROTARY LYE PEELER

The lye solution is heated by steam coils in the peeler tank or by pumping the lye through external heating coils. Adequate circulation and agitation of the lye solution through and within the peeler tank is essential for good temperature control and uniform peeling. An enclosed peeler reduces danger to operating personnel and decreases heat losses from the equipment.

Lye peelers are usually closely coupled to preheaters, if used, and to washers for removing lye-affected peel. Adequate waste disposal must be provided for all peeling operations. Clearances from local authorities should be obtained before proceeding with purchase and installation of any type of peeler. Disposal of spent lye solution and caustic-containing wash water may be difficult in some areas.

Steam Peeling

Steam peeling is a very satisfactory method for removal of peel from potatoes and is used by a number of the larger processing plants (see also p. 356 and 421). By this method, potatoes are subjected to high pressure steam for a short time. This causes hydration and cooking of the surface tissue which softens and loosens the peel from the underlying tissue. After adequate contact with the potatoes, the steam is released rapidly from the pressure vessel; the potatoes are discharged; and the softened tissue is removed by brushes or water sprays. Barrel-type or multi-roll washers, similar to those discussed above, are used.

Since steam attacks all surfaces of the potato uniformly, the contour or shape of the potato has little effect on the efficiency of peeling. It has been reported (Anon. 1944) that removal of a layer of potato approximately three-sixteenths of an inch in thickness is required for adequate peeling. Steam peeling schedules are easily and quickly adjusted to meet the specific peeling requirements of the potatoes and the product. A few extra seconds of contact with high pressure steam increases the amount of tissue removed and reduces the trimming requirements. Boyer (1950) found that superheated steam at atmospheric pressure was very effective in peeling new and old potatoes. Most processors steam peel to a constant trim requirement to prevent excessive peeling losses.

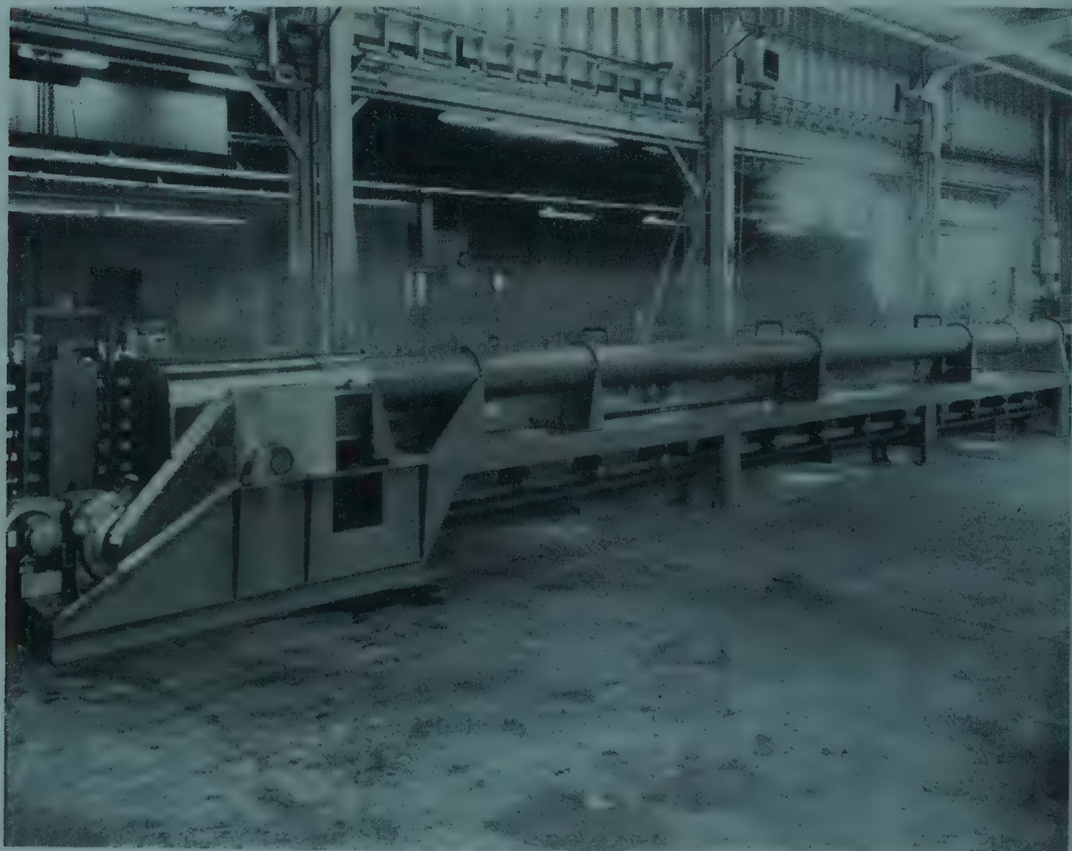
Steam peeling leaves a heat ring on the peeled potato surface. This is not objectionable for a number of processed products. However, in potato chips, the heat ring is still discernible in the finished product and is reported to reduce consumer acceptance. In prepeeled potatoes, enzymatic darkening often occurs under the heat-affected surface layer. During storage of prepeeled potatoes, this surface layer toughens to such an extent that it interferes with the usefulness of the product.

Steam Peeling Equipment.—Equipment used for steam peeling may be either continuous or batch type. For the latter, various sizes of pressure vessels are in common use. These are equipped with a quick-opening charging door and are usually mounted on hollow axles to permit rotation of the peelers during operation and to allow for admission and discharge of steam. After charging with the proper amount of potatoes, the door is closed and steam is admitted until the desired steam pressure is attained. Venting is necessary for removal of air from the retort if proper peeling temperature is to be obtained. Pressures up to 100 lbs. per sq. in. are used.

The retort is normally rocked or rotated slowly to insure even distribution of steam throughout the charge and to aid in removal of loose peel. Pressure is held for 30 to 90 seconds and a total time of 3 to 5 minutes

is required for a complete cycle. The steam supply valve may be closed as the required temperature and pressure in the retort have been reached. The retort exhaust is usually through the opposite hollow axle.

As soon as steam has been vented to the outside and atmospheric pressure attained, the retort is opened and the charge is dumped. The potatoes are then moved to the washer where cooked and softened tissue is removed. Normally one operator is required for charging and operating



Courtesy of Cleaver-Brooks Co.

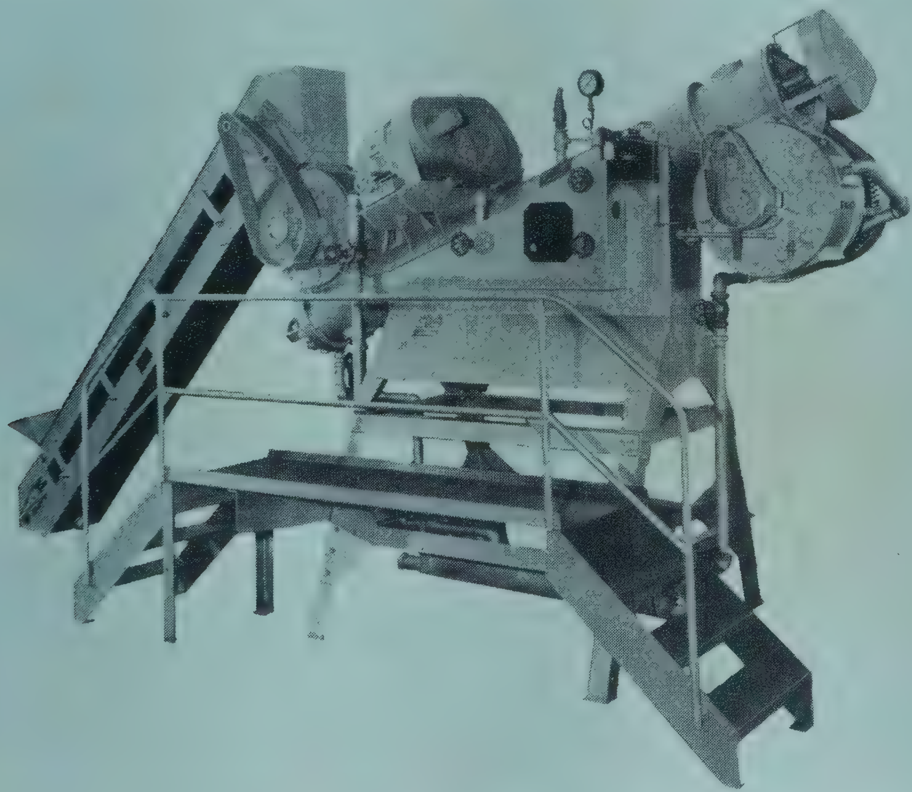
FIG. 48. CONTINUOUS PISTON-TYPE STEAM PEELER

the retort, operation of the inlet steam and exhaust valves, and timing the operation. One experienced operator can effectively peel several thousand pounds of potatoes per hour.

Continuous steam peelers are also used in the potato processing industry. They have high capacities, and require little labor for operation but the initial cost is rather high as compared with the simpler batch type peelers.

One type of continuous steam peeler has been described by Stateler (1947) and Slater (1951). It receives the incoming potatoes between

gasketed pistons properly spaced on an endless metal belt. As the pistons are pulled through a long metal tube at the required pressure, steam is injected into each compartment (Fig. 48). Steam pressure in each compartment is rapidly reduced to atmospheric pressure when the product reaches the discharge end of the tube. The rapid reduction in pressure aids in removing the peel from the potato as the potatoes are discharged from the peeler. The potatoes then pass through a washer to complete peel removal.



Courtesy of Food Machinery and Chemical Corp.

FIG. 49. CONTINUOUS HIGH PRESSURE SCREW-CONVEYOR TYPE STEAM PEELER

Another type of continuous steam peeler has been in use for a number of years (Anon. 1945). It has a specially constructed multi-pocket inlet and outlet valve system, permitting the charging or emptying of the potatoes into or from a tubular steam pressure chamber which is traversed by a screw conveyor (Fig. 49). Once the potatoes are in the chamber, the contact time with the high pressure steam is regulated by the screw conveyor. About 30 seconds' retention time with 60 lbs. per sq. in. steam pressure in the chamber has been used in peeling potatoes. Potatoes

are discharged from the peeler into a washer to complete removal of the peel by water sprays.

Brine Peeling

Brine solutions maintained near the boiling and saturation points have been used for peeling potatoes only on a limited scale (Anon. 1943). Since evaporation is constantly taking place care must be exercised to prevent over-saturation and crystallization. Immersion times required for adequate peeling are reported to range from 3 to 10 minutes. The cost of salt for peeling a given amount of potatoes is estimated to be about one-fifth to one-half that for lye. Brine solutions present less of a hazard to operating personnel than lye but are corrosive to equipment. Any salt on the peeled product does not require neutralization and may reduce enzymatic discoloration of the peeled surface. In some instances, lye and salt have been used together.

Flame Peeling

Flame peeling makes maximum use of high temperatures for removal of the skin from potatoes by actual charring or carbonization. In flame peeling, potatoes are passed through a flame or refractory oven which subjects all surfaces of the potato to about 2000°F. for a period of 15 to 30 seconds. The short retention time greatly reduces the depth of the heat ring on the peeled product.

Doolin (1945) reported on the use of flame peeling of potatoes for chips. Peeling losses ranged from 3 to 16 per cent (average 9.5 per cent) compared with abrasion peeling losses of 12 to 20 per cent for the same lot of potatoes. In other comparative tests, Hemmeter (1946) found about 20 per cent peeling loss using abrasion peeling and about 10 per cent for flame peeling where potatoes were exposed for 15 seconds at 2100°F. Friselle (1943) indicated that in using flame peelers difficulties are encountered in controlling temperature, that they are noisy, and that they require considerable maintenance and servicing. Flame peelers have not been used very widely for peeling potatoes but are used quite extensively for peeling onions and peppers.

The problem of conveying potatoes through the intense heat of the furnace is the principal one facing builders of flame peelers. Rapid temperature changes cause refractory surfaces to disintegrate. Rotating drums, screws or rolls must be constructed of heat resistant material and must rotate the potatoes as they pass through the flame or heated area. No matter what device is used for conveying the potatoes, its useful life is limited by the effects of high temperature. Fuel costs are high in consideration of the amount of work that is done.

Although the major part of the outside peel can be removed by the flame peeler-washer combination, deep set eyes and blemishes are not effectively removed. Von Loesecke (1943) reported that radiant heat from glowing refractory surfaces was more efficient than flame peeling. Eye removal requires considerable trimming, especially if sprouting has started. This reduces the economies reported for flame peeling potatoes.

Oil Peeling

Heated oil at 300° to 400°F. has been employed to remove the peel from potatoes. If mineral oils are used they must be completely removed or undesirable oily odors will be imparted to the product. Vegetable oils have also been used.

TRIMMING

Subsequent to peeling and washing, potatoes require hand trimming to remove residual skin, eyes, discolored areas, black spot, disease and insect injury, and sunburned and greened material. The amount of trimming required will depend on the efficiency of the peeling operation and the product requirements.

There are many types of trimming tables available. The most common one used for potatoes is the straight-flow type in which a belt carries the untrimmed potatoes along each side of the table. Each potato must be picked up, trimmed and placed on a center belt which carries the trimmed potatoes to the next processing step. With this table it is not possible for potatoes to pass through the trimming operation without being inspected and handled individually. With other belt arrangements it is necessary to pick up and trim only those potatoes that have defects. Inspection is aided by rollers or other devices that turn the potatoes so that all sides can be observed without handling.

After trimming, potatoes may pass over a size grader or may be conveyed directly to the next processing operation. A surge tank may be used at the end of the trimming line to even the flow of peeled potatoes to the processing lines.

DISCUSSION

It is not possible to make any over-all generalizations about peeling losses or cost figures for any of the various peeling methods. This is due to the many variables in the peeling operation, the potatoes and the product. Peeling losses are less for large potatoes than for smaller potatoes. Potatoes of higher grade and quality will normally yield more peeled product per 100 lbs. of unpeeled stock. There are also differences between varieties due to eye depth, types of skin, color and shape. The age

of the potato also affects peeling loss, usually being less for new potatoes than for storage potatoes of the same size and variety. Rot and blemish removal not only increases the trimming waste that must be cut away, but increases the cost by the extra trimming labor required.

The peeling requirement for the product is an important consideration. Peeling losses and cost increase if a speck-free product is desired as compared with a peeled product permitting a few flecks of skin or other minor defects. Some products and processes can tolerate the presence of minor peel fragments—others cannot. Another factor of importance in any peeling method is its flexibility of control and adjustment to fit the needs of a processing line.

A number of publications are listed in the bibliography of this chapter, which discuss the foregoing factors, relating peeling losses, production costs and other factors with different peeling methods, when using different grades and varieties of potatoes for specific products.

A few of these articles illustrate certain specific points of interest. Peeling economy as influenced by size and grade of potatoes was studied by Werner (1950), using hand peeling. U. S. No. 1 potatoes were separated by size in three lots: small, 79 gm.; medium, 160 gm.; and large, 311 gm. Each succeeding size had approximately twice the weight of the previous one. Samples were also divided between sound and blemished potatoes. The yield of peeled product per ten pounds of sound potatoes was about 7.7 for small, 8.2 for medium, and 8.4 lbs. for large. There was approximately two per cent reduction in peeled potato yield when the blemished potatoes were used. They also reported that the yield of peeled potatoes from U. S. No. 2 and culls was approximately 81 and 76 per cent, respectively. The peeling losses and time required for hand peeling almost doubled when shifting from large to small sized potatoes. Although the cost of large potatoes is about twice that of small ones, it did not offset the difference in peeling labor costs. Although hand peeling is not used in potato processing, these findings may be useful in evaluating other peeling methods. Mazzola (1943) and Mazzola and Auburn (1946) observed and calculated peeling losses for different grades of potatoes. Product yields for U. S. No. 1, and unsorted potatoes containing only 40 per cent U. S. No. 1's were determined. The percentage yield of peeled product from 40 per cent U. S. No. 1's by abrasion peeling was 47 per cent, by high temperature lye peeling 75 per cent, by batch steam peeling 56 per cent and salt brine 27 per cent. When using U. S. No. 1 potatoes, the product yields reported were 68 per cent by abrasion peeling, 85 per cent by high temperature lye peeling, 74 per cent by batch steam peeling and 54 per cent by salt brine.

Wright and Whiteman (1949) found that peeling losses vary consider-

ably by variety when peeled by abrasion. In one experiment peeling losses obtained for several varieties ranged from 14 to 31 per cent. In a second test, losses ranged from 8 to 21 per cent. The same varieties remained in the higher or lower loss groups in each test. Brown (1944) found a range of peeling losses for different varieties by both explosion and abrasive peeling. In the former, losses varied from 7.6 to 12.8 per cent while in abrasion peeling, they ranged from 11.9 to 22.7 per cent for the same varieties and in the same order. Wager *et al.* (1945) reported 7 per cent peeling loss for new potatoes and 20 per cent for old potatoes using lye for peeling. Results obtained by lye and abrasion peeling are shown in Table 25 (Harrington *et al.* 1956). These results were obtained

Table 25

COMPARATIVE PRODUCT YIELD AND TRIMMING LABOR WITH LOW TEMPERATURE LYE PEELING AND ABRASION PEELING[1]

Potato Variety	Low Temperature Lye		Abrasion Peeling	
	Product Yield	Trimming Labor Unit	Product Yield	Trimming Labor Unit
	Per cent		Per cent	
Russet Burbank	86	$1^1/_3$	75	$3^1/_3$
Early White Rose	75	1	91	1

[1] Estimates based on good potatoes having a minimum of rot, bruises and growth cracks when prepared as French-fry cuts.

in a large potato prepeeling plant over a two-year period of operation.

Abrasion peeling losses and trimming costs are usually higher than those for other peeling methods. These losses generally vary from 15 to 30 percent. However, losses from 10 to 50 per cent have been reported. For the potato chip industry, abrasion peeling losses of about 10 per cent are considered normal. This is due to product requirement and the use of select quality potatoes.

Eidt and MacArthur (1944) compared different peeling methods and reported peeling losses averaging about 25 per cent for abrasion peeling, 18 per cent for steam peeling, 17 per cent for lye peeling and 8 per cent for brine peeling. They also found that the nonabrasive peeling methods tested reduced hand trimming by about 35 per cent and estimated that most of the labor costs in the preparation of potatoes for processing is for peeling and trimming labor. This may represent 50 per cent of the total cost of some dehydrated products. Dunlap (1944) reported a considerable reduction in labor and material costs in changing from abrasion to lye peeling.

The use of a combination of lye and brine gives results similar to lye peeling alone. However, brine without the addition of lye is generally

considered to be less effective. Flame and radiant peeling losses are generally quite low—about ten per cent—but other factors such as equipment and maintenance costs have deterred widespread use of this method.

Woodroof *et al.* (1948) indicated that wetting agents and detergents were useful in overcoming peeling inhibition caused by dirt, fuzz and wax. They also recommended use of salt in combination with lye for peeling. Salt raises the boiling point of the peeling solution and increases the effectiveness of the low concentration lye solution. A patent issued to Miller and Andrews (1946) covers the use of 5 to 10 per cent lye with enough salt to raise the boiling point to 220°F. Lower lye concentrations in the peeling media have been effectively used with new potatoes as compared with those from storage.

Greig (1956) compared the economic factors involved in abrasion and lye peeling as used by the pre-peeled potato industry. In this study, the increased costs of lye peeling were nearly balanced by the increased cost of trimming abrasion-peeled potatoes. The fixed costs for equipment and installation were higher for lye peeling than for abrasion peeling. A very comprehensive comparison of the costs of lye and abrasion peeling has recently been made by Greig and Manchester (1958).

The rapid increase in the amount of potatoes being processed is causing processors to look more critically at their peeling losses and trimming costs. An over-all reduction of only one per cent in the peeling losses of the entire potato processing industry would result in savings of several hundred thousand dollars. This field will be more extensively investigated in the future and procedures that are more economical in respect to both raw material and trimming costs will undoubtedly be developed.

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Ora Smith

Potato Chips

YIELD OF CHIPS

Specific Gravity

In selecting potatoes for processing into chips it is exceedingly important that tubers of high specific gravity or dry matter content be chosen. The specific gravity of potatoes varies considerably between varieties grown under similar conditions and within the variety when grown under different soil, cultural and environmental conditions. It was shown in Chapter 4 that specific gravity of potatoes is determined largely by a combination of factors such as variety, soil texture and reaction, mineral nutrition of the plant, soil moisture, cultivation and weed control, spray program, vine killing, temperature during the growing season and maturity. Rogers *et al.* (1937) stated that the weight of chips made from Russet Burbank, Warba and Chippewa varieties increased with the percentage increase in dry matter of the slices. Whiteman and Wright (1949) showed that the yield of potato chips increased as potatoes of progressively higher specific gravities were cooked. Smith (1950A, 1950B and 1951A) separated each of nine varieties into specific gravity groups and showed that for every increase in specific gravity of 0.005 there is approximately an increase of one per cent in yield of chips. If a 100-lb. lot of peeled potatoes of 1.060 specific gravity yields 27 lbs. of chips a similar lot of 1.085 specific gravity would produce about 32 lbs. as shown in Fig. 50. Kunkel *et al.* (1951) and Kunkel *et al.* (1952) showed that the relation of low specific gravity of potatoes to yields of chips also existed on large scale processing plant operations. Russet Rural potatoes were separated by a brine solution into two lots of 1.0916 and 1.0777 specific gravity. Unpeeled potatoes of 1.0916 gravity produced yields of chips of 24.32 per cent and those of 1.0777 gravity yielded only 21.41 per cent.

Variety

The selection of potato varieties as a factor determining yield of chips is very important to the processor. Varieties vary inherently in their total solids content when grown under the same conditions and, hence affect yields of chips obtained from them. It has been shown that environmental conditions also affect total solids of potatoes and in a subsequent section the effects on yields of chips will be shown. Whiteman

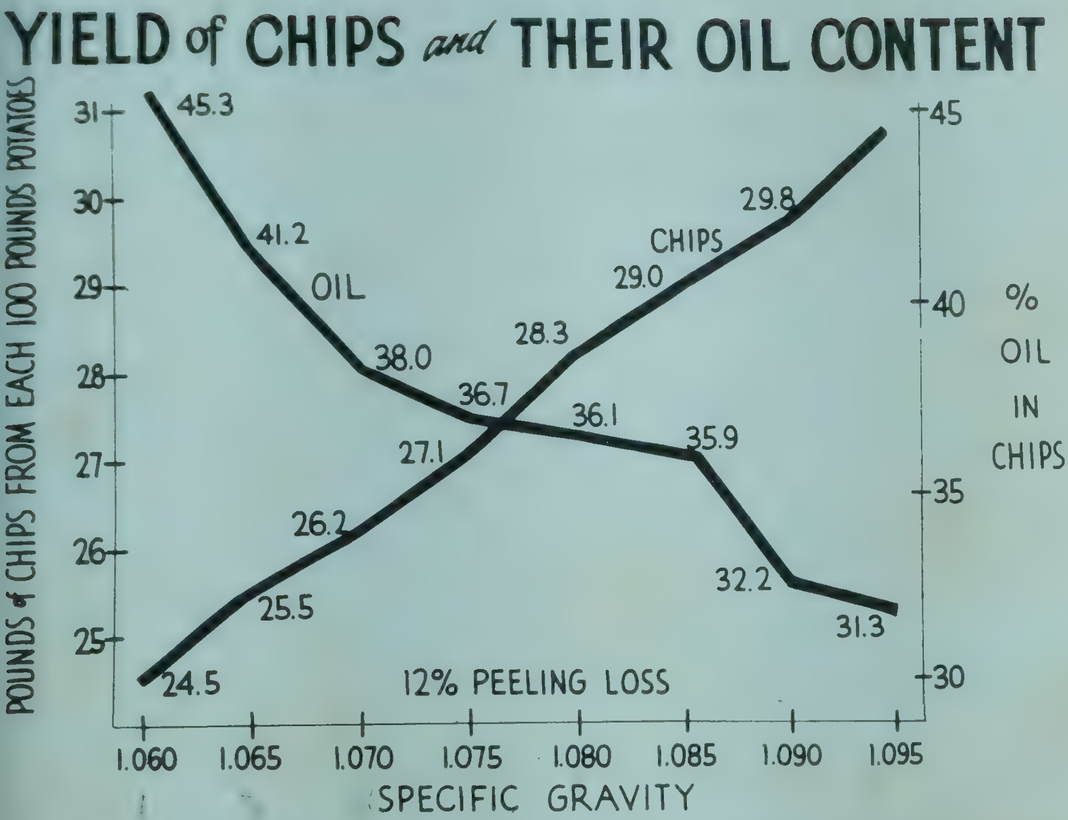


Fig. 50. Relation of Specific Gravity of Potatoes to Yield and Oil Content of Chips

Table 26

YIELD OF CHIPS FROM SIX VARIETIES OF POTATOES[1]

Year	Variety					
	Chippewa	Irish Cobbler	Katahdin	Russet Burbank	Russet Rural	Sebago
	Per cent of Peeled Potatoes					
1947	30.7	32.4	31.7	36.6	33.8	34.6
1948	30.4	33.2	32.9	34.8	33.0	30.9

[1] From Whiteman and Wright (1949).

Table 27

EFFECT OF POTATO VARIETY AND LOCATION WHERE GROWN IN NEW YORK[1] ON YIELD OF CHIPS

Variety	Washington County	Onondaga County	Allegany County
	Per cent of Peeled Potatoes		
Kennebec	29.8	31.7	29.6
Chenango	28.7	29.7	31.1
Katahdin	28.0	31.7	29.7
Canoga	28.5	31.7	30.8

[1] From Smith (1951D).

Table 28

EFFECT OF VARIETY AND PLACE WHERE GROWN ON YIELD OF POTATO CHIPS[1]

Variety	Oneida County, N. Y.	Genesee County, N. Y. (Muck Soil)
	Per cent of Peeled Potatoes	
Katahdin	32.1	33.7
Pungo	32.7	34.9
Sebago	33.0	31.5
Irish Cobbler	30.8	34.6
Keswick	31.9	35.0
Kennebec	33.1	35.1
Cherokee	31.3	31.7
Canso	33.3	33.0

[1] From Smith (1952A).

and Wright (1949) found differences in yield of chips from several varieties in a two year period as shown in Table 26.

Smith (1950A, 1951D, 1952A) found differences between varieties in specific gravity and yields of chips when the varieties were grown in the same area as well as differences between areas in New York as shown in Tables 27, 28 and 29.

Maturity

Fully mature potatoes are highly desirable for chipping. Yield and quality of chips and keeping quality and conditioning of the tubers all are affected by maturity. Usually as potatoes become more mature they increase in specific gravity. This, in turn, affects the factors mentioned above. Maturity can be obtained best by early planting, late harvesting and killing of potato vines rather slowly.

Until adequate methods are developed for holding the main crop harvested in the late growing states for year round processing, it is necessary to use immature potatoes from the South and West for the April to July processing period. Some strides have been made in these areas toward delaying harvest of potatoes for chips and this has resulted in improved yield of chips. Choice of variety of early harvested immature tubers from these areas is very important. Sebago and Irish Cobbler from the South and White Rose from southern California supply most of the potatoes during these months. They should not be held in storage very long before processing. They are, in general, of relatively low specific gravity and, therefore, produce relatively low yields of chips.

In the late growing areas early planting usually results in higher specific gravity of tubers on any one date of harvest and therefore, higher yields of chips. Delayed harvest also tends to result in increased specific gravity of tubers and greater yields of chips.

TABLE 29

EFFECT OF POTATO VARIETY ON YIELD OF CHIPS[1]

Variety	Per cent of Peeled Potatoes
Essex	27.96
Chippewa	28.03
White Rose	28.81
White Rural	29.90
Sebago	30.03
Katahdin	30.78
Russet Rural	31.41
Russet Burbank	31.95
Irish Cobbler	33.38

[1] From Smith (1950A).

Cultural Factors

Irrigation.—In most cases where irrigation supplements normal rainfall, potatoes are of lower specific gravity than those which were grown without irrigation. Even in semiarid areas where irrigation is necessary to grow potatoes, heavy applications of water, especially late in the growing season, result in potatoes of lower specific gravity than those irrigated moderately or lightly.

There are exceptions to the above statements, however. During seasons of abnormally high temperatures and low rainfall it has been shown that irrigation lowers the soil temperature to temperatures more conducive to potato growth. Smith (1956) found temperatures of irrigated soils averaged 72.8°F. during late July and early August, 1955, while unirrigated soils averaged 76° during the same period. Average specific gravities of tubers of five harvests from irrigated areas were 1.068; from unirrigated soils it was 1.061. Keeping the soil well supplied with moisture during hot weather will result in lower soil temperatures and probably in higher specific gravity tubers which produce higher yields of chips.

Fertilization.—Potatoes which have been heavily fertilized, particularly with nitrogen, usually are of lower specific gravity than those receiving lesser amounts of these nutrients. Fertilizers have an effect on maturity and often influence specific gravity of tubers. Depending upon other growing conditions, these differences sometimes are very small and at other times quite extensive.

These differences in specific gravity bear a direct relation to the yields of chips made from the potatoes (Eastwood and Watts 1956C; Smith 1957). Large applications of potash also usually reduce specific gravity of potatoes and yields of chips, although use of sulfate of potash results in potatoes of higher specific gravity and higher yields than equal quantities of potash in the form of muriate of potash (Eastwood and Watts 1956B; Kunkel and Smith 1956).

Spraying or Dusting.—Treatment of potatoes for the control of insects and diseases also has an effect on quality of potatoes for chips. Some insecticides, such as DDT, control insects so well that maturity of the plants and tubers is greatly delayed. Hence, the tubers form their final chemical composition under considerably different environmental conditions, especially temperature, than if they had matured and died earlier. This can and often does affect composition and specific gravity of tubers and subsequently the yield and quality of chips. Potatoes sprayed with various insecticides result in differences in specific gravity of the tubers and resultant yields of chips. Omitting DDT from the last two fungicide spray applications increases the specific gravity slightly. Lead arsenate and nicotine sulfate in combination, as well as parathion sprays further increase specific gravity of tubers and chip yield (Smith 1957).

Vine Killing.—With late maturing plants it becomes necessary to kill the vines either with chemicals, heat or mechanically. This too may affect specific gravity of tubers and resultant yield of chips. Usually the later the plants are killed, the higher the specific gravity of the tubers and the greater the yield of chips (Smith 1954B; Akeley *et al.* 1955).

Methods of Measuring Specific Gravity of Potatoes

Although many factors collectively determine the specific gravity of potatoes grown during any season or in any locality, it is fairly easy to determine the gravity of the tubers. The conventional method formerly was to weigh a representative sample of the potatoes in air and then weigh the same sample immersed in water. The specific gravity of the sample was then calculated as follows:

$$\frac{\text{weight in air}}{\text{weight in air minus weight in water}} = \text{specific gravity}$$

For instance, if a sample of potatoes weighed 22 lbs. in air and 1.75 lbs. under water, the specific gravity for this sample would be

$$\frac{22}{22 - 1.75} = 1.086$$

This method has been simplified by the development of a scale by the Toledo Scales Company which indicates by a pointer, the specific gravity of the sample without the necessity of any calculation.

A much cheaper and more rapid and accurate method was made possible by the development of the potato hydrometer by Smith (1950A and 1950C). This hydrometer shown in Fig. 51 is calibrated for the determination of an eight-pound sample of potatoes. The potatoes chosen at random from the field, load or storage, after weighing, are placed in

FIG. 51. POTATO HYDROMETER FOR MEASURING THE SPECIFIC GRAVITY OF POTATOES

the wire basket and the basket suspended from the bulb of the hydrometer. When the sample and apparatus are placed in a container of water, the correct specific gravity and dry matter readings are obtained at the water level on the chart in the tube. Hundreds of these hydrometers are now in use in the potato chip industry in the United States, Europe, Australia, New Zealand and Africa. It is estimated that if all potatoes for the chip industry in the United States were selected with the use of the potato hydrometer and averaged 0.005 higher in gravity than those now used, that the increase in chips produced from the same weight of potatoes would be approximately 30 million lbs.

Separating Potatoes by Specific Gravity for the Chip Industry

It is normal for potatoes to vary in specific gravity; tubers from any one plant or "hill" of potatoes differ in their total solids content. The determination of specific gravity or total solids of potatoes by the potato hydrometer or other methods is comparable to the candling of eggs. It

is an excellent, rapid method of determining mealiness of potatoes before they are cooked, canned or dehydrated and it also predicts mealiness of French fries and yield of dehydrated potatoes and potato chips.

It is even more important, however, to separate potatoes into two or more specific gravity groups for purposes of more uniform mealiness, yields of processed product and quality of the finished product. By the use of this process it is possible to detect interior quality without injury to the potatoes, and consumers and processors can then be supplied with what they want for best quality of the finished product (Smith and Nash 1940; Smith 1951B and 1951C). Some of the first investigations along this line (Haddock, 1938; Haddock and Blood, 1939; Blood and Haddock, 1939; Clark *et al.* 1940 and Smith and Nash, 1940) showed that even though wide differences in composition existed between individual tubers, that they can be graded to produce a more uniform cooked or processed product by means of specific gravity separation. Smith and Nash (1940) suggested to potato chip manufacturers, growers, buyers and housewives that the low gravity potatoes be separated from those of the same lot of higher gravity so that each lot, when properly used, would result in greater satisfaction to the consumer. Sodium chloride solutions of various concentrations are most often used for such separations. If potatoes are to be stored or shipped after such separation, it is best to rinse the brine from the tubers.

Specific gravity grading of potatoes for the fresh market has been shown to be a profitable and worthwhile enterprise in several widely separated areas in the United States (Kunkel, 1950; Greig 1950; Greig and Smith 1951; Rasmussen, Smith and Johnson 1952; Smith 1953A and 1955B; Merchant and Gavett 1957). Several machines have been developed for the separation of potatoes in a continuous line (Kunkel *et al.* 1952; Pflug *et al.* 1955), and the results of trials of one of these showed that 12,000 lbs. of potatoes per hour could be separated accurately into two specific gravity groups (Kunkel *et al.* 1952).

COLOR OF POTATO CHIPS

Probably the most important problem in the potato chip industry is the maintenance of desirable color of chips throughout the year. Control of color, which is necessary for a standard product, is difficult because the color of the potato chip is determined by the chemical composition of the potato tuber. Chemical composition of tubers is dependent on many uncontrollable environmental factors in the field and also conditions during transit and storage. Fluctuations in the chemical balance of the tubers due to variety, maturity, storage temperature and other factors are expressed in the color of the chips.

Some control of chip color is possible in the processing plant during cooking. Such factors as temperature of fat or oil used, thickness of slice and length of frying period have an effect on color of chips.

It has been known for many years that sugars, especially reducing sugars, in potatoes, have a marked effect on chip color. Potato varieties vary considerably in their ability to accumulate reducing sugars during growth and storage. Those varieties which have a relatively high content of sugars cannot be used successfully for chip processing. Varieties which accumulate large percentages of sugars at low temperature storage and which cannot be reconditioned adequately at 70° to 80°F. are soon discarded by the industry. Although it has been mentioned in the older literature that the color of potato chips is a result of caramelization of the sugars in potatoes, recent research indicates that potato chip color is a result of the "browning reaction" or Maillard reaction. Sugars participate in the browning reaction but other constituents of the potato such as amino acids, ascorbic acid and other organic components must be present before color formation occurs.

Reactants Causing Color in Potato Chips

Some investigators ascribe the dark discoloration which often appears in potato chips to the presence of reducing sugars and to changes which occur to the sugars during heating (Thornton 1940; Denny and Thornton 1941 and 1942). However, recent research has indicated that reducing sugars alone are not responsible for such discoloration in chips. The reactants causing color in potato chips can be extracted by boiling water and they can be returned to the potato system unchanged. When potato slices are extracted with hot water and the extract is readsorbed by the extracted slices, brown chips are produced which are of the same color as chips made from untreated potatoes.

When hot water extracted potato slices, which would remain white when fried into chips, were immersed in a glucose solution before frying, practically no color was produced in the chips (Pyke 1946). When similar slices were immersed in a solution of glycine, no color appeared on subsequent frying. However, when slices were subjected to a solution containing both glucose and glycine, subsequent frying produced potato chips of dark brown color. In no case did any sugar or amino acid produce browning when used alone. Similar results have been obtained by soaking pure cellulose filter paper disks in glucose alone, glycine and other amino acids and a combination of glucose and one or more amino acids.

The degree of fluorescence of the brown pigments formed in processed potatoes, and also by amino acid-sugar combinations in vitro, has been found to vary with the pH of the final solution (Pyke 1946).

A hot water extract of potato chips showed colloidal properties believed to be due to soluble carbohydrate fractions such as pectin and starch (Pyke and Patton 1946). Extraction with hot 50 per cent alcohol yields an almost white, amorphous hygroscopic powder which is readily soluble in cold water and has a sweet taste. It is high in browning reactants as shown by potato chip tests and its partial composition is as follows:

	Per cent
Ash	14.2
Reducing sugar (glucose)	36.4
Total nitrogen	3.7
Amino nitrogen (formol)	2.3
Amino nitrogen (Van Slyke)	2.1
Ammonia nitrogen	0.35

Chemical constituents other than reducing sugar must be present before any color forms under the conditions which are used to fry potato chips. Some of these constituents are the amino acids and ascorbic acid. In a synthetic system of filter paper disks and pure chemicals, color is formed as a combination of reducing sugars or other sugars with amino acids, ascorbic acid and other chemicals normally in the potato. Evidently potatoes practically always contain sufficient quantities of these latter chemical constituents for color formation. It is only when reducing sugars are increased that color formation occurs or intensifies. Up to a certain level, the higher the concentration of reducing sugars, the darker the color formed. Although the amino acids will react with ascorbic acid to form dark colors without sugar, evidently neither the amino acids nor ascorbic acid is present in the potato in high enough concentration to cause unacceptably dark colors in the absence of sugars, Smith *et al.* (1954).

With glucose alone, regardless of concentration, little or no color develops in fried filter paper disks. When glycine, an amino acid, is added to the glucose solution, the filter paper disks turn dark during frying. The higher the concentration of either the glycine or the reducing sugar, glucose, the darker the color of the disk. Similar results are obtained from the reaction of glycine and sucrose. Colors develop, but in each case at the same concentrations, the colors from glycine-glucose are darker than those from glycine-sucrose. Ascorbic acid alone, however, develops color in filter paper disks during frying. When various concentrations of glycine and ascorbic acid are used in the disks, they are progressively darker as concentrations of either or both constituents are increased. Similar results were obtained with each of 17 amino acids in addition to glycine.

Effect of Storage of Potatoes on Chip Color

That sugars accumulate markedly in potatoes stored at low temperatures was shown first by Muller-Thurgau (1882). Reducing and non-reducing sugars accumulate when potatoes are held at 46°F. after having been at room temperature. Loss of starch occurs simultaneously. Shifting potatoes from low to higher temperatures reverses the chemical reactions.

Because of inherent varietal differences it is very difficult, if not impossible, to determine at which temperature most sugars accumulate. Hopkins (1924) found about 0.7 per cent on a fresh weight basis at 41°F. storage for 50 days. Wright (1932), however, states that an average of about two per cent accumulates in several varieties held at that temperature. Wolff (1926) studied the sugar-starch equilibrium of stored potatoes over a wide range of temperatures and found that starch synthesis is effective between 46° and 90°F. and that sugar formation predominates below 46° and above 90°F. This sugar formation at temperatures above 90° may account for the apparent ability of some tubers to accumulate sugars when stored at fairly high room temperature, Smith (1950B). Varietal differences or environmental differences during the growing season may render the tubers capable of accumulating sugars even at relatively high temperatures. Chips from potatoes stored at temperatures between 32° and 37°F. are darker and less desirable than those from tubers stored at 60°F. (Sweetman 1930). Potatoes most satisfactory for chips are those stored at 50° to 60°F. At 40°F. storage the products are undesirably brown and barely edible; from 32° or 36°F. storage they are extremely undesirable because of dark brown color and burned taste (Wright *et al.* 1936). Rogers *et al.* (1937) state that the most obvious effect of storage was the increase in sugar and darkening of chips.

The critical low storage temperature for development of off-color in potato chips is about 45°F., a safe temperature being 46.5°F. according to Denny and Thornton (1942). They found that at 46.5°F. sprout development is more extensive and develops two months earlier than in those stored at 45°F. Vapors of methyl alpha naphthaleneacetate and other sprout inhibitors retard sprout development of potatoes during storage at high temperatures and can be used to extend storage life of tubers at temperatures sufficiently high to avoid dark color chips made from them.

Color of potato chips correlates best with the reducing sugar rather than non-reducing or total sugar content of the raw stock (Denny and Thornton 1940 and 1941; Thornton, 1940). In comparing a large number

of sugar determinations with color of chips made from those tubers, Wright and Whiteman (1951) found that chips with the most desirable color came from potatoes averaging 0.18 per cent reducing sugar. Potatoes making chips that were barely salable averaged 0.92 per cent reducing sugar. Smith (1955A and 1956) found that in most instances acceptably colored chips may be made from potatoes of less than 0.2 per cent reducing sugars on fresh weight basis. Only one of 156 samples with reducing sugars above 0.25 per cent, produced acceptably colored chips. As reducing sugars accumulate above this figure, color of chips darkens very rapidly. With further accumulation no further darkening of chips occurs from potatoes with more than 1.25 per cent reducing sugars. Shallenberger (1955) analyzed four varieties of potatoes at several dates of harvest and after certain periods of storage at 32°, 40°, 50° and 80°F. for total sugars, reducing sugars, non-reducing sugars, total nitrogen, protein nitrogen, total soluble non-protein nitrogen, amino nitrogen, basic nitrogen, amide nitrogen and ascorbic acid. Only the reducing and non-reducing sugar content consistently correlated with color of chips. Later work by Shallenberger *et al.* (1958) also indicates that both reducing sugars and sucrose determine potato chip color. Multiple correlation of potato chip color (Rd), versus the reducing sugar and sucrose contents of raw potatoes yielded a correlation coefficient of 0.983.

The color of chips made from tubers stored at 32°F. was lighter than those from tubers stored at 40°F. Chips made from tubers stored for a prolonged period at 40° became darker with length of storage. Tubers stored at 50° and 80°F., however, resulted in lighter colored chips with prolonged storage. The concentration of ascorbic acid diminished with prolonged storage at 40°, 50° and 80°F.; the lower the temperature, the lower the concentration of ascorbic acid. All nitrogen fractions increased in concentration with prolonged storage at a given temperature.

Habib and Brown (1956 and 1957) found high correlation between light colored chips and low reducing sugar content of the tubers. Low basic amino acids and low reducing sugars, particularly pentose sugars, in potatoes are associated with light color potato chips.

Effect of Variety of Potatoes on Chip Color

Selection of good potato varieties for processing into chips is important to the processor. Potato growers interested in producing raw stock for chip processing also should consider the varieties best suited for the industry as well as varieties that produce well under their growing conditions. Some varieties inherently accumulate sugars and other chemical constituents that contribute to dark color in chips and, therefore, are not to be considered for chip processing. Such varieties as Green Mountain,

Pontiac, Bliss Triumph, Ontario, Houma, Erie, Essex, Mohawk and Warba when grown and stored under usual conditions produce chips too dark for commercial use. On the other hand, varieties which usually produce chips of good to excellent color, unless mishandled in transit or storage are Canus, Kennebec, Chippewa, Russet Rural, Russet Burbank, Smooth Rural, Katahdin, Sebago, Pungo, Yampa and Norkota. Cherokee and Irish Cobbler also are quite good. Some of the newer varieties that look very promising for good chip color are Saco, Delus, Merrimack and Plymouth. Whiteman and Wright (1949) rated six varieties grown in 1947 for color of chips from lightest to darkest as Russet Rural, Sebago, Russet Burbank, Chippewa, Katahdin and Irish Cobbler. The same varieties grown in 1948 were rated as Sebago, Russet Rural, Irish Cobbler, Chippewa, Russet Burbank and Katahdin. Smith (1951D) found that when four varieties were grown in three widely separated areas in New York State in 1950, that best color chips were made from Kennebec, then Katahdin, Chenango and Canoga. In the 1957 season varieties which produced lightest color chips were Merrimack, Delus, Russet Burbank, Russet Rural, Saco and Katahdin, Smith (1958). Shallenberger (1955) found that Kennebec and Russet Rural produced lightest chips and Katahdin and Green Mountain the darkest. The two varieties producing the lightest colored chips also had the lowest content of reducing sugar.

Effect of Maturity of Potatoes on Chip Color

It is commonly known by chip processors that the more mature the potatoes are when harvested the easier they are to handle, store and recondition to light colored chips. Immature tubers not only lose more weight and shrivel in storage but their chemical composition is different from those more mature. This change in composition usually makes them more difficult to store so that light colored chips will be produced after conditioning. Shallenberger (1955) found that more mature tubers of four varieties of potatoes produced lightest chips not only on the day of harvest but after storage at several temperatures for as long as eight months. Generally at 50°F. storage, the reducing sugar content of immature potatoes is higher than those potatoes which are more mature. There also are differences, however, in the composition of several of the nitrogen fractions between the mature and less mature tubers.

Smith (1957) showed that a greater degree of maturity as brought about by date of planting has an effect on chip color. The earliest date of planting resulted in lightest color chips and the latest planting date produced the darkest chips. Similarly, obtaining a greater degree of maturity by delaying harvest often increases specific gravity of tubers and results in lighter colored chips.

It is well, therefore, to allow potatoes to mature as much as possible before harvest, providing the delayed harvest does not subject the tubers to temperatures below 40°F. in the field before or during harvest, Smith (1958).

Effect of Other Cultural Conditions on Chip Color

Several additional cultural factors during the growing season have an effect on color of chips made from potatoes. These include irrigation or soil moisture, fertilizers, chemical weed control, spray program for control of insects and diseases, application of sprout inhibitors, application of chelating chemicals and killing vines.

Irrigation or Soil Moisture.—Results obtained by increasing the soil moisture by irrigation will depend on the rainfall, soil type, time when moisture was applied and amount added. Obviously, if rainfall plus irrigation amounts to more moisture than plants can utilize for maximum growth it may result in potatoes of low specific gravity and chips of dark color. During the 1956 growing season in Western New York, Smith (1957) found that unirrigated potatoes resulted in chips considerably lighter in color than those which were irrigated. Lightly irrigated potatoes produced lighter colored chips than those that were irrigated heavily. On the other hand, during a hot, dry growing season, Smith (1956) found no consistent differences in color of chips from potatoes which had been irrigated compared with those which received no additional water. Records of soil temperatures showed that irrigated areas were several degrees cooler than those not irrigated. The lower soil temperature probably has a counteracting effect on the greater absorption of water, resulting in tubers of about the same specific gravity and chips of similar color.

Fertilization.—Application of fertilizers often influences chip color. In most potato growing areas greatest yield response is obtained from application of nitrogen in complete fertilizers rather than from the phosphate and potash portions. Nitrogen promotes extensive vine growth and prolongs the growing season. As a result potatoes are not mature at harvest and, therefore, are likely to produce dark chips subsequent to 40° storage and also they are more difficult to recondition at higher temperatures. Smith (1957) found that potatoes grown with 50 lbs. nitrogen to the acre in a complete fertilizer produced tubers which made lighter chips than those from plants which were fertilized with 75 and 150 pounds of nitrogen per acre. Eastwood and Watts (1956A) state that the use of extra nitrogen fertilizer above that needed to support adequate growth does not consistently and definitely improve chip color (see also p. 77 and 227).

Little is known of the effects of phosphate fertilizer applications to

potatoes on color of chips. In most instances phosphate fertilizers promote maturity in potatoes and slightly increase specific gravity of tubers. There is some indication, however, that large phosphate applications may result in tubers that produce slightly darker chips, Kunkel and Smith (1956).

Potash applications affect both yield and quality of tubers. The amount of potash applied as well as the source of potash has an effect on quality of the tubers. Very little information is available, however, on the effect of potash on color of potato chips. Kunkel and Smith (1956) obtained indications that heavy applications of potash result in potatoes which produce lighter colored chips than those with lower amounts.

Chemical Weed Control.—Application of chemicals for control of weeds may have an effect on potato chip color although little evidence is available. Eastwood (1952) reported slight but not significant increase in the dark color of chips from potatoes grown in areas where weeds were controlled with pre-emergence applications to the soil of 800 and 1200 lbs. cyanamid to the acre and 3-p-chlorophenyl-1-1-dimethylurea (CMU) at 1 and 2 lbs. per acre. No chip color effects were obtained from applications of Crag Herbicide I at 5 lbs. per acre, 90 per cent sodium trichloroacetate at 25 lbs. to the acre and Premerge at 2 gal. per acre. Through a period of eight years, trials with pre-emergence applications of dinitros such as Sinox General, Dow General, Sinox P E and Dow Premerge for weed control Smith (1954A) found no effects on color of chips.

Spraying Plants for the Control of Insects and Diseases.—Application of insecticides and fungicides to plants in the field may have an effect on color of potato chips. Without good control of these pests, early death of plants occurs, yields are reduced and processing quality impaired.

On the other hand, with proper application of several of the many good insecticides and fungicides, potatoes continue to grow, remain green and do not die or mature. As a consequence the chemical composition of these immature tubers often is such that they result in darker colored chips. DDT is one of the most efficient and widely used insecticides which results in high yields of potatoes. However, it also delays maturity and hence affects processing quality of the tubers. Smith (1950D) obtained lighter colored chips from potatoes which had received no DDT than from those which had been sprayed with DDT ten times. It was also found, Smith (1956 and 1957), that omitting DDT from the last 2 or 3 fungicide sprays results in lighter color chips than those sprayed with DDT or parathion all season. Spraying with lead arsenate and nicotine sulfate results in chips of intermediate color. Smith (1951D) found practically no differences in chip color from potatoes which had been sprayed with the following fungicides: Bordeaux mixture, Dithane D-

14 or liquid Parzate. All were as light or lighter in color than those chips from unsprayed plants (see also p. 228).

Field Application of Sprout Inhibitors.—Sprout inhibitors applied to plants have a marked effect on subsequent sprout growth of potatoes in storage. Conflicting data have appeared as to the effect of one of the sprout inhibitors, maleic hydrazide, on color of chips made from the treated potatoes. Smith (1951D) found no difference in color of chips made from Irish Cobbler potatoes unsprayed compared with those sprayed with maleic hydrazide several weeks before harvest. Likewise Kennedy and Smith (1953) working with seven varieties found no difference in color of chips from plants sprayed with maleic hydrazide compared with those not receiving this chemical. Neither concentration of maleic hydrazide nor date of application resulted in any change in chip color or in reducing sugar content of the tubers. Similar results were reported by Highlands *et al.* (1952). On the other hand, Salunkhe *et al.* (1953) report that a foliage spray application of maleic hydrazide resulted in lighter color chips of Russet Rural, Irish Cobbler and Sebago varieties (see also p. 151).

Killing Potato Vines.—Killing potato vines also may affect color of chips. Before the extensive use of such efficient insecticides as DDT it was not necessary to kill potato vines for table stock or processing potatoes; insect injury apparently brought this about. Evidently plant food was translocated from the leaves and stems to the tubers while the insects were slowly killing or "maturing" the plants. If the plants are killed early during warm weather, the specific gravity of tubers is low and color of chips often is dark. On the other hand, if the efficient insecticides prevent extensive insect damage the plants continue to grow and are, as far as chemical composition is concerned, very immature at harvest time. These potatoes also are likely to produce dark chips especially after storage. Hence, the necessity and advisability of killing vines (see also p. 235).

When vines are killed or removed by rotobeating or other mechanical means, there is little or no opportunity to transfer food from tops to tubers. Consequently, the tubers are of low specific gravity and of different chemical composition than those which mature normally. It is best, therefore, to kill potato vines slowly, if possible, or to kill them as late as possible. Smith (1956) found that chips made from potatoes which were grown during a hot, dry season and were not killed, were lighter in color than those from plants which had been killed either by cutting off the vines or by spraying with a chemical vine killer. Akeley *et al.* (1955) found that tubers of an early variety, Irish Cobbler, made as light colored chips when killed on August 15 as they did when killed at any later date. Late varieties such as Sebago, Katahdin and Kennebec,

TABLE 30

EFFECT OF FOLIAR APPLICATIONS OF CHEMICALS ON COLOR[1] (RD) OF POTATO CHIPS[2] HARVESTED SEPTEMBER 26, 1956[3]

Spray	Sept. 27	Oct. 5	Nov. 2	Jan. 7
	Date of Frying			
Sodium gluconate	23.8	16.3	9.7	24.3
Sodium bisulfite	23.0	16.7	7.9	23.9
Sodium acid pyrophosphate	27.4	17.0	7.8	22.5
Chloro isopropyl phenyl carbamate	27.2	15.8	7.8	18.9
Untreated	27.4	15.6	7.3	17.3

[1] The higher the number the lighter the chip color. Less than 16.0 is not acceptable. Rd determined on Hunter color meter.
[2] From Smith (1957).
[3] Stored at 40°F. on Sept. 28; reconditioned at 70°F. since Nov. 2.

however, produced lighter colored chips when killed later. Irish Cobbler and Kennebec tubers made acceptable colored chips at all harvests. Katahdin tubers, on the other hand, made chips too dark to be acceptable from all harvests except the last. This indicates that chips with satisfactory color can be made from some varieties when they are relatively immature. Color of chips from most varieties, however, improves as the potatoes approach maturity.

Sometimes late killing of vines or late harvesting of potatoes results in darker colored chips than those killed or harvested earlier. This darkening of chips from late harvests undoubtedly is due to lower temperatures prevailing late in the season (Smith 1956). Potatoes were harvested on nine dates from August 15 to October 29. At the first seven harvests, up to September 26, all potatoes made light colored chips on the day of harvest. Only 6 of 24 lots harvested on October 3 produced chips of acceptable color. The average air temperature during the week preceding harvest on October 3 was 52.4°F., lowest air temperature was 31.2°F. and average minimum air temperature was 39°F. None of the 18 lots harvested on October 29 produced chips of acceptable color. Air temperatures during the week preceding this harvest averaged 45.7°F., lowest air temperature was 28.5° and average minimum air temperature was 33.6°F. These results show that it is very important to harvest potatoes for chips before they are subjected to low temperatures in the field either before or after digging.

Foliar Application of Chemicals.—Chemicals added during the growing season may affect chip color. Smith (1957) has applied a number of sequestering, chelating and reducing chemicals as sprays to plants in the field several weeks before harvest. There is some indication that several of these chemicals may change the chemical composition of the tubers in such a way as to improve chip color as shown in Table 30 (above).

Improving the Color of Potato Chips

On many occasions it becomes almost impossible for the processor to make light colored chips acceptable to the trade without some treatment of the slices in the chip plant. Although the processors choice of a suitable variety of high specific gravity has been made and the potatoes have not been stored at low temperatures, occasionally it is impossible to condition the tubers so that they will produce light colored chips. It is at such times that the processor is interested especially in some treatment which will prevent or reduce the formation of dark chips.

Chemical Treatment of Potato Slices.—Patton (1948) patented a process of extracting the browning reactants from potato slices before frying. The slices are immersed for various lengths of time in hot aqueous solutions of alkaline earth salts such as calcium chloride, calcium sulfamate and magnesium chloride in concentrations from 0.1 to 0.005 molar before

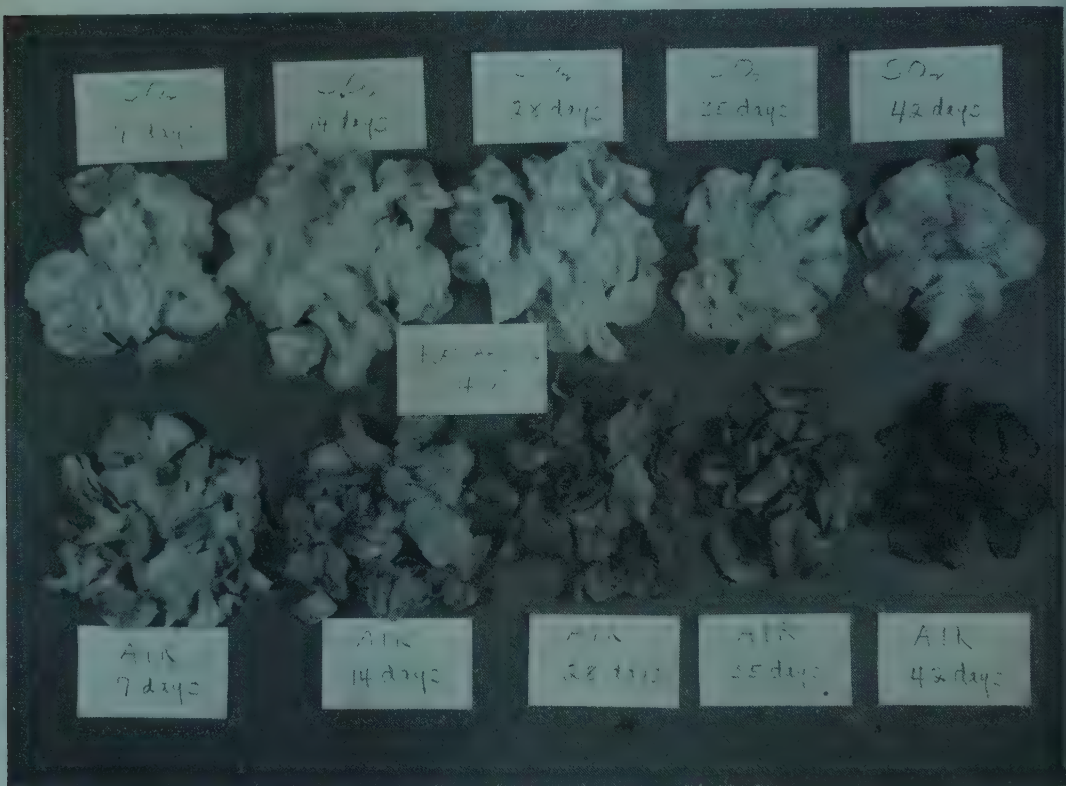


FIG. 52. EFFECT ON CHIP COLOR OF SO_2 TREATMENT OF POTATOES BEFORE STORING THEM AT 40°F.

Potatoes fried after 7, 14, 28, 35 and 42 days storage at 40°F.

frying. Dipping potato slices for three minutes in 0.25 per cent solution of calcium chloride at just below the boiling point extracts sufficient browning reactants to result in light colored chips after frying. Smith (1950E) showed that attractive light colored chips could be made from raw stock

of high reducing sugar content after treating with sodium bisulfite. Potato slices are dipped, for one minute in 0.25 per cent solution of sodium bisulfite at 180–200°F. just before frying. Later, Smith (1957) improved this method by using the following procedure: slices are dipped for one minute in a solution of 3.1 lbs. sodium citrate, 10 oz. sodium bisulfite and 0.4 pint 85 per cent phosphoric acid in 50 gal. of water held at 180–200°F. With this method no loss of flavor or off-flavors have been detected. Chips treated with this method resist development of rancidity when placed in an oven at 145°F. Smith (1958) greatly simplified the treatment of potatoes for the improvement of chip color by treating whole unpeeled potatoes of low reducing sugar content with sulfur dioxide gas. Potatoes are treated for 24 hours with a low concentration of sulfur dioxide in air and then placed at 40°F. storage. Tubers treated with sulfur dioxide produce acceptably light colored chips for several months at 40°F. storage; those not treated are much too dark after 14 days storage. Xander (1952) patented a process whereby potato chips of uniform color may be produced the year round regardless of the variety or the reducing sugar content. Potato slices are immersed in a bath of sulfur dioxide and then washed with water to remove sulfur dioxide, furfural and reducing sugar before frying.

Whiteman (1951) suggested soaking potato slices for one or two minutes in slightly acidulated water (0.044 per cent hydrochloric acid) at 145°F. just before frying. Although the chips were somewhat lacking in the usual distinctive potato flavor, they were acceptable in color and flavor and had no off-taste.

Brown discoloration of chips may be prevented or reduced by immersing potato slices in hot water. Dexter and Salunkhe (1952A) treated potato slices for one minute in water at 158°F. which resulted in potato chips with practically no browning. Townsley (1952) dipped potatoes in water 6 to 7 minutes at 153° to 163°F. and obtained satisfactory color when the potatoes were made into chips. In such treatments, however, some flavor is lost as a result of leaching out sugars, nitrogenous compounds and other constituents of the potato. Dexter and Salunkhe (1952B and 1952C) attempted to obtain differential extraction of materials so that reducing sugars might be removed without excessive leaching of other desirable constituents of the potato. Slices were treated with phosphoric and hydrochloric acid solutions of pH 2.0 before frying.

OIL CONTENT OF CHIPS

The oil content of potato chips is very important to chip processors. Oil is a fairly costly raw material used in chip processing and determines to a considerable extent the cost of the finished chip. It is highly desirable

to maintain a fairly low level of oil in chips. High oil content not only is costly to the processor but often renders the chips greasy or oily and hence, less desirable to consumers. On the other hand, it is possible to make chips so low in oil that they lack flavor and seem harsh in texture. Therefore, it is important to study the various factors which affect oil content of chips. Some of the most important factors affecting oil content of chips are: (1) specific gravity or dry matter content of potatoes, (2) partial drying of slices of raw tubers in air before frying, (3) leaching raw slices with hot water, hot sodium chloride solution or other chemical, (4) thickness of slices, (5) type of fat, (6) temperature of fat during frying and (7) length of frying time.

Specific Gravity

Most chip processors are aware of the differences in specific gravity between certain varieties grown under the same conditions and also differences within any one variety when it is grown under several environmental conditions or areas. It has been known for some time that these differences in specific gravity of tubers will influence the yields when made into chips. Whiteman and Wright (1949) found that specific gravity of tubers also influences the oil content of chips made from them.

TABLE 31

EFFECT OF SPECIFIC GRAVITY OF POTATOES ON YIELD AND OIL CONTENT OF CHIPS[1]

Specific Gravity	Yield[2] of Chips Per cent	Oil Content of Chips Per cent
1.065	26.7	45.3
1.070	27.8	38.0
1.075	29.4	36.7
1.080	29.5	36.1
1.085	31.0	35.9
1.090	33.1	32.2

[1] From Smith (1951E). [2]Yields from peeled, sliced potatoes.

With White Rose, Calrose and Russet Burbank varieties the oil content of chips decreased as specific gravity of tubers increased. Smith (1950B, 1951A, 1951E, 1952B and 1953B) showed that as the specific gravity of potatoes increased, yields of chips also increased and oil content of chips decreased as shown in Table 31. These potatoes were of the same variety grown in the same field, separated by salt solutions into specific gravity groups.

Kunkel *et al.* (1951) indicated the practicability of using high specific gravity potatoes in a commercial chip processing plant. Potatoes were separated into two specific gravity groups with a large scale gravity separator and fried separately. Yields of chips were higher and oil con-

TABLE 32

EFFECT OF PARTIAL DRYING OF POTATO SLICES ON YIELD, OIL CONTENT AND FRYING TIME OF CHIPS[1]

Time Slices Were in Oven at 145°F. Minutes	Loss in Weight in Oven Per cent	Chip Yield Per cent[2]	Oil Content of Chips Per cent	Frying Time Minutes
Fried in[1] Shortening				
0	0	29.2	37.6	2.50
5	11.8	28.9	37.5	2.12
10	24.0	27.8	36.2	1.94
15	36.4	26.9	32.0	1.50
Average of Cottonseed Oil, Peanut Oil and Corn Oil Fryings				
0	0	28.6	37.6	
5	12.7	28.6	37.7	
10	25.4	27.6	35.6	
15	35.8	26.9	34.8	

[1] From Smith (1951B and 1951E). [2] Yields from peeled, sliced potatoes.

tent was lower from the high specific gravity tubers. The high gravity lot, averaging 1.0916, was made into chips with 32.64 per cent fat and the low gravity lot of 1.0777 produced chips of 37.05 per cent fat. Ng *et al.* (1957) found a positive relation between specific gravity of tubers and their calcium content. It is to be expected then that a positive relation exists between calcium content of tubers and oil content of chips. Johnson (1957) also found that the fat content of chips is increased by low specific gravity tubers.

Partial Drying of Raw Sliced Potatoes Before Frying

Drying potato slices before frying lowers the oil content of chips. Specific gravity or dry matter content of potatoes has a marked effect on the oil content of chips made from them. In other words, the lower the moisture content of potatoes the lower the oil content of chips processed from them. Smith (1951B, 1951E) dried potato slices in an oven and also under radiant infrared heat for various lengths of time before frying. After five minutes drying, with a loss of 8 to 12 per cent moisture, there is very little change in the oil content of chips. When slices are dried for ten minutes or more, with moisture loss of approximately 25 per cent, the oil content of chips decreases. There is a resultant reduction of 6 to 8 per cent in oil consumption. However, as oil content drops, yield of chips also decreases. This may be of value in promoting low oil content chips or for reducing bleeding of oil in the retail package. Length of frying time also is reduced by the predrying treatment.

Leaching Slices

Leaching raw slices with hot water or hot solutions of various chemicals affects the oil content of chips. This process has been advocated for re-

moval of reducing sugars so that lighter colored chips will be produced. This method, however, results in increased uptake of oil during subsequent frying. Stutz and Burris (1948) found that treating potato slices in hot solutions of sodium chloride reduced the oil content of chips. Slices dipped for two minutes in 7.5 per cent sodium chloride solution at 185°F. produced chips of decreased oil content and of satisfactory flavor. Smith (1951B) found that treating potato slices for one minute in five per cent sodium chloride solution at 180°F. resulted in chips with 93 per cent as much oil as those rinsed in cold water, when they were fried in cottonseed, peanut or corn oil and 88 per cent as much when they were cooked in shortening. Chips treated in the five per cent salt solution and then cooked have the correct amount of saltiness without any additional salt applied.

Table 33

EFFECT OF ONE-MINUTE TREATMENT OF POTATO SLICES ON YIELD, OIL CONTENT AND FRYING TIME OF POTATO CHIPS[1]

Dip Used	Concentration	Temperature	Chip Yield[2]	Oil Content of Chips	Frying Time
	Per cent	°F.	Per cent	Per cent	Minutes
Cold water	...	Cold	28.2	36.8	2.35
Water	...	180–200	28.7	40.0	2.19
Salt	5	180–200	28.6	34.3	2.21
Salt	7.5	180–200	29.1	29.2	2.12
Salt	10	180–200	28.7	27.7	2.14
Sodium bisulfite	0.25	180–200	27.7	37.6	2.29
Citric acid	2.0	180–200	27.4	38.1	2.33

[1] From Smith (1951B).
[2] Yields from peeled, sliced potatoes.

Thickness of Slices

Slice thickness affects oil content of chips. Processors often vary the thickness of slices in order to obtain light colored chips at a certain oil temperature and length of frying time. Johnson (1957) found that decreasing slice thickness from $^1/_{12}$ in. through $^1/_{15}$, $^1/_{18}$, $^1/_{21}$ to $^1/_{24}$ in. increased oil content of chips from 43.85 through 44.68, 46.81, 47.61 to 49.93 per cent.

Type of Fat or Oil

Oil content of chips also may be influenced by the type of fat or oil used although this is not considered to be a major factor.

Woodruff and Blunt (1919) compared Wesson oil and lard and found that fat content of chips fried in oil ranged from 34.40 to 37.10 per cent and from 38.18 to 38.95 per cent for those fried in lard. Whiteman and Wright (1949) obtained variable results between potato crops of two

years. In the 1947 crop of six varieties, oil contents of chips were as follows: cottonseed oil 35.8 per cent, peanut oil 36.8 per cent, shortening 37.2 per cent and corn oil 38.5 per cent. In the 1948 crop, however, it was 36.1 per cent with shortening, 36.7 per cent with peanut oil, 38.2 per cent with cottonseed oil and 38.3 per cent with corn oil. Johnson (1957) also found that cottonseed oil produced significantly higher fat content in chips than hydrogenated lard. On the other hand King *et al.* (1936) found that fat absorption by chips was about the same for all kinds of fat.

Temperature of Fat During Frying

When processors have difficulty in making light chips from raw stock rather high in reducing sugars, they often alter the temperature of the frying fat or change the length of frying time or both. Usually the higher the frying temperature the less oil absorbed. Williams (1951) attributes this to the fact that as temperature increases, the density of the oil becomes less so that a smaller proportion of oil is absorbed in a given time. Some investigators consider the frying temperature to be the most important external factor in making good chips (Rogers *et al.* 1937). The best frying temperature to use, of course, may vary with the variety, the specific gravity and the reducing sugar content of the tubers. As sugar content increases, the range of frying temperatures becomes narrower and usually it is necessary to lower the temperature under these conditions. There is a tendency for the amount of fat absorbed to increase slightly with a decrease in the temperature of the fat. Sweetman (1936) states that fat absorption by chips does not increase with lower temperatures until fat temperatures drop below 250°F. Lowe *et al.* (1940) found fat absorption was higher at initial frying temperatures of 302° and 347°F. than at 401° and 419°F. Fat temperatures at the end of the frying period were 31° to 43°F. below the initial temperatures. Whiteman and Wright (1949) showed that the oil content of chips made from the Chippewa and Russet Rural varieties increased as the inital fat temperatures during frying decreased. Johnson (1957) also found that as frying temperatures decreased from 400°–340° to 370°–310° to 340°–280°F., the oil content of chips increased. On the other hand, Woodruff and Blunt (1919) found no relation between oil content of chips and frying temperatures of 410° to 374° and 374° to 338°F.

Length of Frying Time

This factor is closely associated with frying temperature of the oil. The two factors together have an effect on oil content of chips. When chips remain in the oil for fairly long periods, oil absorption usually will

be greater than for shorter periods of frying. Ordinarily a decrease in cooking temperature is compensated for by an increase in cooking time.

FLAVOR OF POTATO CHIPS

It is important that potato chips possess a pleasing and desirable flavor. Flavor of chips like that of most foods is descriptive only in subjective terms usually as a result of panel taste or flavor tests. Little is known as to the constituents of the potato that contribute to the flavor of potatoes regardless of their methods of preparation. Flavor of potato chips is even more complicated to analyze and more difficult to describe than flavor of boiled, baked or mashed potatoes. Potato chips possess flavors inherent in the raw potato as changed by high temperatures for a short time. In addition, potato chip flavor is made up of the flavor of fats, oils or shortenings and of salt. Few persons can detect any differences in flavor between varieties of potatoes and their methods of culture. It is possible, of course, for potato growers to make applications of certain chemicals, especially insecticides and herbicides to plants or the soil in which they are grown, which may impart undesirable off-flavors to the potatoes. Potato chips consist of a high per cent of fat and the fat in chips is subject to changes such as reversion, oxidation and rancidity, which result in undesirable, off-flavor chips. Flavor also may be improved by the addition of salt and other additives such as monosodium glutamate and protein hydrolyzates. In addition to the natural flavor of potato chips, many processors add other flavor materials such as barbecue flavor, various types of cheese and others.

Type of Fat or Oil

Very little is known about the effect of type of fat or oil used in chip processing on the flavor of chips. It probably is of minor importance since most frying fats and oils used by the industry are rather bland and do not contribute greatly to chip flavor. King *et al.* (1936) detected from palatability tests that chips fried in highly refined peanut, cottonseed and corn oils were preferable to those fried in several types of lard. More recent research, however, has emphasized that chips fried in deodorized, hydrogenated and stabilized animal fats are as acceptable in flavor as those made from vegetable oils.

Decomposition of Frying Fats and Oils

When fats are heated to high temperatures such as in potato chip frying, three general chemical reactions may occur simultaneously; namely, hydrolysis, polymerization and oxidation. Oxidation and polymerization are probably the two most important changes occurring in heated oils.

Hydrolysis of fat represents a minor portion of the total problem. Much study has been made of this reaction probably because of the ease of measurement of free fatty acids which arise from this reaction. Oxidation of hot frying fat is much more important and usually results in rancidity. Polymerization of fats occurs to some extent in some deep fat frying operations and this will be discussed later.

When oil decomposes on exposure to heat for long periods it becomes darker in color, flavor becomes less bland, free fatty acid content increases, iodine value may decrease, AOM value decreases, smoke point decreases and other changes occur.

Color Change.—As the fat is heated it changes color. This color change can be measured with a Lovibond colorimeter by matching the color of the oil or fat with red and yellow glass plates made to definite color standards. Fresh unheated oils may vary in the Lovibond reading but they will darken during the frying operation. An oil may have an initial color of 6 red and 35 yellow on the Lovibond scale and still be considered satisfactory after use if the reading is as high as 50 red. When oil is badly decomposed by misuse, the red reading may be 700 or higher. This color results from the chemical reactions causing breakdown of the oil during heating. Apparently there is no evidence that the absence of color pigments improves frying properties and it is recognized that dark colors are developed in the fat after several hours of use (Lantz and Carlin 1938; Carlin and Lannerud 1941; Robinson *et al.* 1940).

Free Fatty Acid Content.—As a fat or oil is used for frying potato chips, a chemical reaction takes place resulting in the development of free fatty acids. This reaction of the fat with the moisture from the potatoes is known as hydrolysis. A good quality fresh fat or oil should have a free fatty acid content of 0.05 per cent or less. As it is heated or used the free fatty acid content may increase to as high as 0.75 per cent in a well handled chip processing operation, but could go as high as 7 to 8 per cent if the oil has been badly abused and broken down. In well operated chip plants free fatty acid content of fats and oils would seldom rise above 0.5 per cent. If free fatty acid above this figure is found in a chip operation it would be well to search for the possible causes and try to correct them.

Flavor Changes in the Fats.—Most fats and oils used in the potato chip industry have a very bland, neutral flavor when fresh. Upon being heated and during frying they become less bland in flavor and may develop burned, scorched or rancid flavors. If the fat is heated at excessively high temperatures it may develop a scorched flavor. Rancid flavors are the result of combining oxygen from the air with the fat. This reaction is known as oxidation. Flavor of used fats and oils, therefore, may also be an indication of the amount of breakdown.

Smoking Point.—Fats and oils used in the chip industry have initial smoke points above 450°F. As the fats are heated and used the smoke point becomes lower as a result of the fat breaking down into components having lower smoking points. Smoke point tests often are used as a measure of oil breakdown although it is not considered reliable for this purpose.

Oxidation and Development of Rancidity.—Chip processors must consider the changes which fats and oils undergo on aging or use and which lead to the development of undesirable flavors. Rancidity and flavor reversion in fats and oils or in the chips may result in serious economic losses. Quality and stability of fats and oils have been improved greatly during recent years. Shelf life of chips will be dependent not only on the fat or oil used but on such factors as the potato which is used, the frying equipment, fat turnover in the kettle, packaging, exclusion of light, adequacy of filtering the oil and other methods of handling the fat or the chips.

Effect of Potatoes.—There appears to be no factual information available on the part played by the potatoes in development of rancidity. A number of opinions of processors, however, suggest that some varieties of potatoes and some methods of growing and storing potatoes result in chips of greater stability than others. Development of rancidity is not influenced, however, by specific gravity of potatoes although low specific gravity tubers produce chips of higher oil content (Smith 1953C).

Frying Equipment.—The type of frying equipment, method of heating the oil, type of metal comprising the kettle, pipes, valves and connections, stack "drip back" and aeration of oil during frying all have an influence on breakdown of frying fats and oils. Heat speeds up the chemical reactions which result in breakdown. The less heat applied to the fat and the more uniformly the fat is heated in all parts of the kettle, the less will be the breakdown and the longer it will remain in acceptable condition. Peterson (1955) showed that the oil deteriorated more rapidly during frying of potato chips for five days at 385° than at 350°F. Free fatty acid in the fat at 385°F. was 56 per cent higher and the color approximately 300 per cent more red than of the fat heated to 350°F. It also was shown that chips fried at 350°F. did not develop rancidity until twelve days at 140°F. whereas those fried at 385°F. became rancid in nine days. This emphasizes the value of lower frying temperatures to maintain the fat in better condition and to produce chips with longer shelf life.

In many chip frying operations local over-heating in parts of the kettle also causes fat to deteriorate although the overall temperature in the kettle appears normal. In some methods of heating kettles, undoubtedly certain areas are of much higher temperature than others. Peterson

(1955) demonstrated the effects of local overheating of oil by heating one kettle of oil by direct flame to 350°F. and another kettle was heated to the same temperature by means of an oil bath surrounding the kettle of cooking oil. No local overheating was possible in the kettle heated in an oil bath but the temperature of the fat right over the flame in the direct heated kettle was 583°F. Fat in the direct heated kettle broke down more rapidly as shown by more rapid darkening and development of higher free fatty acid content. Chips from the direct heated kettle developed rancidity in one-half the time of those heated more uniformly.

Effect of Metal Contaminants.—Presence in the fat of minute amounts of certain metals such as copper or copper alloys can also hasten breakdown of oil. Well refined frying fats and oils are practically free from traces of copper, containing from 0 to 0.3 p.p.m. Copper is a very strong pro-oxidant, being effective in concentrations much less than one p.p.m. Copper and copper containing alloys should, therefore, be avoided in kettles, pipes and valves which come in contact with the cooking oil. Fats in contact with those metals or alloys usually develop free fatty acid and darken at a more rapid rate than fats not exposed to these metals. Peterson (1955) found that chips fried in fats in contact with copper or copper alloys had poorer keeping quality, as measured by rancidity development, than chips fried in kettles free of copper. Sometimes the copper contamination is in the fat melting equipment, filtering mechanism or the copper shield of a thermometer bulb somewhere in the oil line or tanks.

Stack "Drip Back."—This may also accelerate deterioration of frying fats and oils. When fat and entrained moisture which cools and condenses in the stack are allowed to drip back into the frying kettle, fat breakdown is hastened. The presence of 0.75 per cent of exhaust drippings (3 oz. per 25 lbs. of fat) in a commercial potato chip frying machine greatly accelerated the rate of fat breakdown as shown by increased foam development, rate of color formation, and, to a lesser degree, the rate of free fatty acid formation (Carlin *et al.* 1954). These changes were confirmed by less desirable flavor and the appearance of the fat. Peterson (1955) found that "drip back" fat from the stack has about five times the red color and ten times the fatty acid content as the fat in the frying kettle. This, of course, would have a tremendous effect on quality of the chips fried in these fats.

Aeration of Oil.—Aeration of oil in the kettle has an effect on oil deterioration. Rate of fat oxidation is tremendously accelerated by exposure to air at high temperature. While potato chips are being fried the surface of the fat is protected by a layer of steam arising from the potato slices. During shut downs or between shifts, however, air comes

into contact with the oil surface either in the kettle or in the temporary storage tank. This causes deterioration of the fat by oxidation. Oil and chip stability can be improved by cooling the fat rapidly as soon as frying is completed and by placing floating aluminum covers over the fat whenever it is not in use. As much as 10 to 15 per cent additional shelf life is obtained for potato chips in this way (Schroeder 1957). Carlin *et al.* (1954) found that this method of protecting oil from oxidation during 72 hours of heating increased shelf life of chips at 145°F. from 4 days to 56 days.

Rate of Fat Turnover.—In most chip processing plants rate of fat usage is very high. Fat is absorbed rapidly by the high production rate of chip frying and is constantly replenished with added fresh fat. This minimizes many potential serious troubles which often arise with slow rates of oil usage. Peterson (1955) found that in a commercial chip plant where turnover of fat was about 100 per cent every 8 to 10 hours there was very little deterioration of fat as measured by color and free fatty acid content.

It may be better, in many instances, where fat turnover is rather slow, to redesign the kettle so that less fat is needed in the kettle at any one time. Despite a high rate of fat turnover, however, Carlin *et al.* (1954) showed that when fat was continuously aerated at frying temperatures by cascading the fat during circulation of the fat through the system the fat deteriorated rapidly.

Filtration of Oil.—Frying fats and oils should be filtered to remove burnt particles, starch grains and other charred material. This may be done by continuous filtering or after each day's or night's frying. This carbonaceous material affects the flavor of the fat and of the chips and also by depositing on the chips it detracts from their appearance. Peterson (1955) found that color of unfiltered fat increased at a faster rate than that of a fat filtered once a day.

The proper filter medium should be used, however, or the process may be detrimental rather than beneficial. Trace metals in filter earth used in filtering fat have been known to promote rancidity of the fat. Although the filter medium removed the fine particles from the fat, it contaminated the fat with metal which accelerated the oxidative reaction, resulting in rancidity of the oil and potato chips.

Peterson (1955) found that salt does not apparently have any harmful effect on frying fat. An accumulation of gum on the sides of the frying kettle, however, will cause the fat to break down and hastens flavor deterioration of the chips.

Effects of Cleaning Compounds.—Cleaning compounds or soap have also contaminated fats and oils when they have not been thoroughly

rinsed from the kettle and other equipment. Soaps and alkaline cleansers, in addition to steam, are used to remove gummy deposits from the frying equipment. When rinsing is not thorough, traces of these cleansing materials can react with the frying fat to form soaps. Peterson (1955) showed that when trisodium phosphate, used as a cleanser, was not thoroughly rinsed from the kettle, the frying oil darkened much more than following adequate rinsing. There was no difference, however, in free fatty acid development of the frying fat. Soap contamination produced similar results.

Effect of Light on Oil Breakdown.—Light also hastens breakdown of oil and of products such as potato chips. When intensity of light to which oil-containing foods such as potato chips are exposed is the same, the ultra-violet, violet and blue regions, those below 4900 Å, promote rancidity the most, while the regions at about 5400 Å and above 7400 Å, promote rancidity the least. The yellow region, near 5700 Å, and the red region, near 6600 Å, are less active than the blue region but nevertheless promote rancidity appreciably more than the green region, Coe (1941A). The regions which are active in catalyzing rancidity seem to correspond with the light absorption regions of the oils. Exclusion of light of all wave lengths, however, is best. Cottonseed oil protected with a green wrapper remained non-rancid as compared with unprotected oil, Coe (1941B).

TABLE 34

CHANGES IN SOME PROPERTIES OF A FAT DURING FRYING[1]

Fat Heated, Hrs.	F.F.A., Per cent	Smoke point, °F.	A.O.M. Value, hrs.	Color[2] Y.	R.	Peroxide Value	Iodine No.	Fat Heated, Hrs.	Keeping Time of Chips at 145°F., Days
0	0.03	425	118	11	1.0	0	64.6	6	96
27	0.15	380	4			4.2		30	6
38	0.22	360	3			6.0		38	4
45	0.27	380	2			4.0		45	6
70	0.41	350	4			5.2		70	3
91	0.79	320	5			3.0		93	4
113	1.01	340	8	40	.94	2.2	58.0	111	5

[1] From Carlin and Lannerud (1941).
[2] Y = yellow; R = red.

Carlin and Lannerud (1941) show in Table 34 some of the changes occurring in a hydrogenated vegetable oil during frying of potato chips and also keeping qualities of the chips.

Polymerization of Fats and Oils.—When oils are subjected to high temperatures for rather long periods they are likely to change by polymerization. Polymerization of fats or oils is the union of two or more

molecules of fat to form a larger molecule. Since this union occurs at the double bond positions it reduces their number and therefore, lowers the degree of unsaturation of the fat. Unlike oxidative polymers which result in rancidity, thermal polymers cannot be detected by any off-flavor or odor. Iodine value is a measure of the unsaturation or double bonds present in an oil. Therefore, as polymer formation proceeds there is a decrease in the iodine value of the fat or oil.

Thermal polymers may be toxic to animals and result in poor nutrition and growth inhibition. Deuel *et al.* (1951) found no adverse effects on growth of either male or female rats when fats, which were heated for eight hours at 401°F. or potato chips containing such fats, were fed to these animals. Melnick (1957) reported on an extensive research project conducted in cooperation with the National Potato Chip Institute and the potato chip industry. Oil samples obtained from 89 commercial chip operations from all over the United States showed that there was about a one per cent decrease in iodine value of oils in frying potato chips on a commercial basis. There is no nutritional significance in this change, however, since it has been shown that an iodine value decrease of as much as five does not result in measurable toxicity.

Flavor Reversion.–Flavor reversion in fats is the formation of objectionable flavor from less oxidation than is required to produce true rancidity. It occurs in certain oils preceding rancidity. Reversion seems inherent in the glycerides of oils and is associated with the presence of fatty acids which contain more than two double bonds, such as linolenic acid. None of the oils used in the potato chip industry in the United States contains linolenic or similar unsaturated fatty acids. Soybean oil contains such acids but it is not used in the chip industry except as a relatively small portion of hydrogenated vegetable shortenings. In hydrogenated shortenings detectable reversion does not occur unless the soybean oil exceeds 25 to 35 per cent. This method for masking reversion reaction has been widely used in industry. Hydrogenated soybean oil in the reverted state has a flavor similar to hay, or fishy or painty odors and leaves an undesirable after-taste in the mouth. The reverted flavor may pass unnoticed while the food is being eaten but later it may become unpleasantly apparent. In inhibiting reversion the expedients usually adopted to enhance stability such as the use of antioxidants, reduction of unsaturation by hydrogenation or packaging to minimize access of oxygen and light are, in general, of little value (Bailey 1946).

Use of Antioxidants to Delay Rancidity.–One of the greatest problems of the potato chip industry and one which results in large chip returns and money loss to chip processors is development of rancidity in chips. Some of the factors contributing to rancidity of chips are exposure to air,

light and high temperature, contamination of oils with metals and poor packages. This explains why rancidity of chips is more of a problem in summer than in winter and of greater importance to chippers in the southern than in the northern part of the United States. It also indicates that chips in transparent bags may become rancid more quickly than those in opaque bags, cartons or cans, because of the greater exclusion of light in the latter containers.

Rancidity develops as a result of oxygen from the air combining with the oil in the chips and forming substances of unpalatable flavor. Any method of handling oil or chips or any material added which would decrease the rate of this reaction would prolong the shelf life of chips. The application of one or more of a number of chemicals known as antioxidants usually retards this process. Antioxidants are acceptors of hydrogen and protect oils and fats by being preferentially oxidized or oxidized first.

Animal fats, such as lard, contain very little if any natural antioxidants and hence, when an antioxidant is added the shelf-life is greatly extended. Vegetable fats and oils, however, contain considerable quantities of natural antioxidant such as the tocopherols and therefore, respond less markedly to added antioxidants. A number of antioxidants such as nordihydroguaiaretic acid (NDGA), propyl gallate, butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT) and others have been found suitable as antioxidants in the chip industry. Butylated hydroxyanisole is one of the best known antioxidants for "carry through" in potato chips. It is most effectively used in combination with other phenolic antioxidants such as hydroquinone and propyl gallate, along with the addition of a synergist such as citric acid (Kraybill *et al.* 1949; Magoffin and Bentz 1949). In a series of experiments extending through several years, it was found that antioxidants such as butylated hydroxyanisole and butylated hydroxytoluene either alone or with propyl gallate and a synergist added to the oil in which chips were fried, delayed rancidity development and greatly extended shelf life of chips (Smith 1950F; 1950G; 1951F; 1952C, and 1953C). A number of hydrogenated vegetable shortenings, vegetable oils and lards were used. Greatest increase in shelf-life was obtained by additions of antioxidants to animal fats, next from vegetable oils and least from hydrogenated vegetable shortenings. When butylated hydroxyanisole was added to vegetable oils and this mixture was added to the fryer at intervals to keep the oil up to starting mark, it was found that in as many as 232 successive batch fryings the butylated hydroxyanisole-fortified oil produced chips with extended shelf-life by delaying rancidity, Smith (1950G). At a taste panel comprised of members of the National Potato Chip Institute, 14 days after chips were fried in

cottonseed oil it was found that 112 persons favored chips fried with butylated hydroxyanisole in the oil, seven favored chips fried without antioxidant and six detected no difference, Smith (1951F). Some of the antioxidant is adsorbed during filtering of the oil by Johns-Manville 503 diatomaceous earth filter aid, Smith (1952C). In a method of improving color of potato chips by the use of sodium bisulfite-treated slices of potatoes, it was found that rancidity of the chips was delayed and shelf-life extended by the sodium bisulfite, Smith (1950E).

Atomizing antioxidants such as BHA on chips just as they are removed from the fryer has further delayed rancidity development and is recommended for commercial use (Smith 1950F and 1950G).

Rancidity in chips is delayed by incorporating one of the antioxidants in the salt that is added to chips (Smith 1950G).

Packaging Materials and Rancidity

Light is an important factor responsible for the development of oxidative rancidity in potato chips. Hence, packages and packaging materials can influence rancidity in chips. Blue and invisible ultra-violet light accelerate the development of rancidity in potato chips, whereas other visible light, such as red and yellow, has little effect. Rancidity-retarding packages may be of any visible color except blue (Morgan 1935). Highly protective, yellow, transparent cellulose films have been developed and utilized for food packaging. Numerous glassine bags for potato chips have been examined and some found responsible for the development of rancidity (Carlin 1948). Chips in single wax glassine bags held at 145°F. became rancid in 4 to 7 days, whereas duplex wax glassine bags prevented rancidity for 10 days (see also p. 272).

Potato chips remained stable for more than four weeks when stable fats and oils and moistureproof paper were used and when they were protected from light. Green colored glassine bags were effective in preventing the development of rancidity in potato chips when exposed to light for short periods (Mitchell 1949).

Some fat-containing food products are packed in containers to which nitrogen is added. This prolongs the shelf-life of the food materials by delaying development of rancidity. This is confined largely to products in cans and undoubtedly it can be done with flexible transparent film with proper equipment. Nitrogen packaging in oxygen-impermeable films probably would extend shelf-life of potato chips.

It was thought that shelf-life of chips possibly could be extended by incorporating an antioxidant in the packaging material. Results of cooperative experiments of the National Potato Chip Institute and a leading glassine manufacturer indicate that there is no clear cut advantage

resulting from the use of butylated hydroxyanisole either in base paper or in the wax film in which potato chips are packaged (Smith 1951G).

Miller and Robertson (1951) were able to extend shelf-life of potato chips by placing in the bags perforated packets containing activated carbon and silica gel.

Improving Flavor of Potato Chips

Some cooked foods are markedly improved in flavor by the addition of monosodium glutamate. Smith (1950H) conducted a series of experiments and taste panels with chips to which only salt was added compared with others which had salt and monosodium glutamate (10 to 1) added. There were 5018 persons who tasted both kinds of chips and voted their preference as follows: 3074 preferred chips treated with monosodium glutamate, 1661 preferred chips with salt only and 283 had no choice. Xander (1952) improved flavor of potato chips by immersing the slices in a protein hydrolyzate derived from raw potatoes. After frying, chips also may be sprayed with a dilute aqueous solution of protein hydrolyzate or treated with a dry powder form.

TECHNOLOGY OF POTATO CHIP PROCESSING

Potato chips are processed in every state in the United States. There are between 400 and 500 chip processing plants in this country, many of them, however, are small establishments. Most of the chips are manufactured in less than 100 processing plants, some having a business volume of over five million dollars annually. In 1957 over 45 million bushels of potatoes were processed by the potato chip industry. This is one-sixth of the total potatoes eaten in this country. The trend in potato utilization by the chip industry is sharply upward. In 1940 less than five million bushels were utilized for this purpose. It is estimated that the per capita consumption of potato chips in the United States is now more than four pounds per year, the equivalent of about 17 pounds of fresh potatoes. Potato chips are the most convenient form of potatoes to serve, requiring no preparation. There is increasing demand in recent years for convenience foods and potato chips meet these requirements. It also is a food item very popular for picnics and it may be served at anytime as a snack food. Potato chips are made plain or flavored with cheese, chili, smoke or barbecue seasoning. They are sliced plain or regular as well as wavy or waffle cut.

Potatoes may be received for processing from storage or direct from the field or the shipper. Early or new crop potatoes usually are utilized from March or April to August. These immature tubers are processed within a week or two after harvest and usually are not stored more than

a few days. Potatoes may be received in 100-lb. burlap bags or pallet boxes of approximately one-ton capacity. Smaller crates sometimes are used. Handling of the potatoes may be by hand or palletized and moved by fork lift trucks. In some plants, potatoes shipped and received in 100-lb. bags are emptied into ton crates for storage.

Processing Procedures

The following procedure is probably the most widely used in the chip industry although there are a number of variations from this.

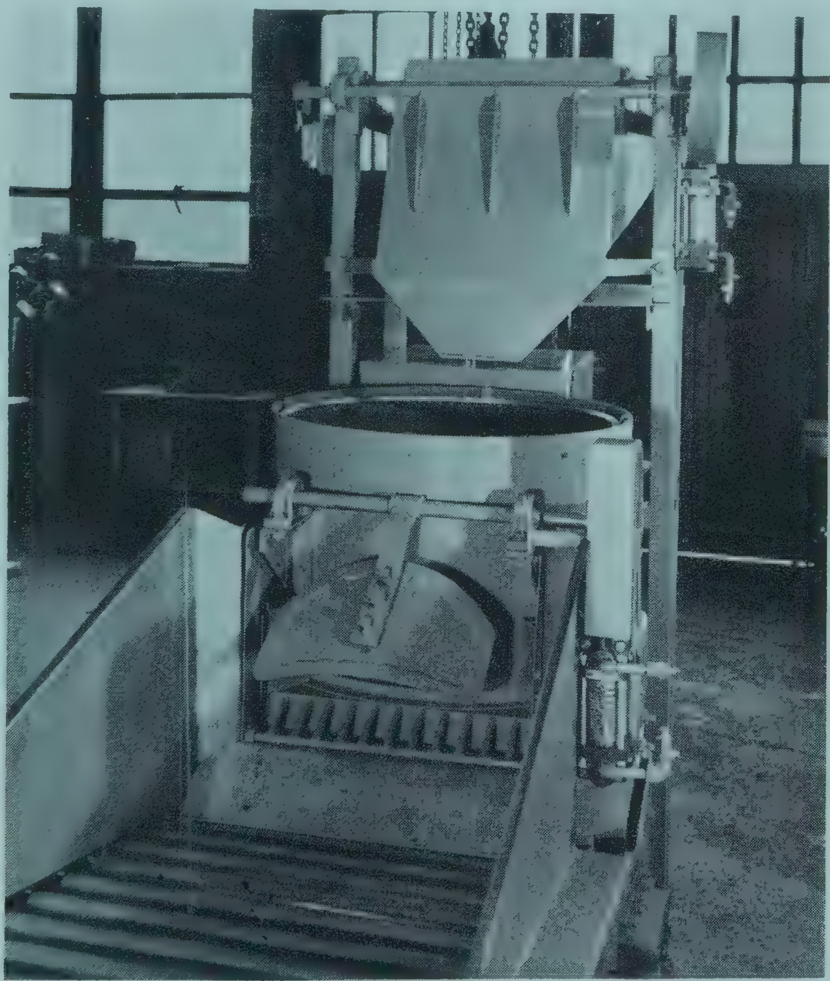
Cleaning and Washing.—Potatoes are dumped into hoppers from which decayed tubers, stones and any trash are removed (see also p. 355). Stones may be picked out by hand or separated from the potatoes by being caught on riffles while rapidly flowing water carries the potatoes to the belt which elevates them into the washer. Specific gravity separation of stones from potatoes has been tried with table salt solutions. Potatoes are elevated into washers and then are peeled in abrasive or carborundum peelers.

Peeling.—Many chip plants use batch drum peelers but newer installations are shifting to continuous type peelers (see also p. 210). Peeling losses usually are higher with the abrasion method than with steam peeling or lye peeling. Nevertheless steam peeling is not used at all in chip plants and lye peeling is employed in only one or two plants. Batch peelers have capacities from 60 to 100 lbs. at each charge. In one type, potatoes are discharged to a weighing hopper from a storage bin or hopper by means of an automatically controlled elevator. The standard size weighing hopper holds approximately 2000 lbs. of potatoes. The weighing hopper controls the feed of potatoes from the bin by alternately starting and stopping the potato elevator when preset weighed batches have been discharged into the weighing hopper. The weighing hopper and peeler combination may be equipped with automatic programming timing device, so that the potatoes may be automatically peeled for a predetermined period of time. The peeling time is variable to provide for differing potato conditions. The doors of the weighing hopper and peeler are controlled by pneumatic cylinders with solenoid pilot valves.

Peeling losses vary with type of peeling, size and shape of potato, depth of eyes and length of storage time of the tubers (see also p. 211 and 220). Small tubers have greater peeling loss than large tubers and newly harvested potatoes have less loss than older potatoes from storage. Average peeling losses range from about 1 to 4 per cent (Carlin 1958). Peeling losses also are higher if the peelers are not properly filled. Losses can be controlled to some extent by varying the length of peeling time.

Peeled potatoes should be washed thoroughly and then inspected for

removal of low grade potatoes. The potato inspection conveyor varies in length and design depending upon individual plant requirements. The standard conveyor is approximately ten feet long and is equipped with a solid conveyor belt of the type used in many canneries for wet vegetable products. The peeled and accepted potatoes are discharged into a stainless steel receiving hopper. From this hopper they are discharged into



Courtesy of J. D. Ferry Co., Inc.

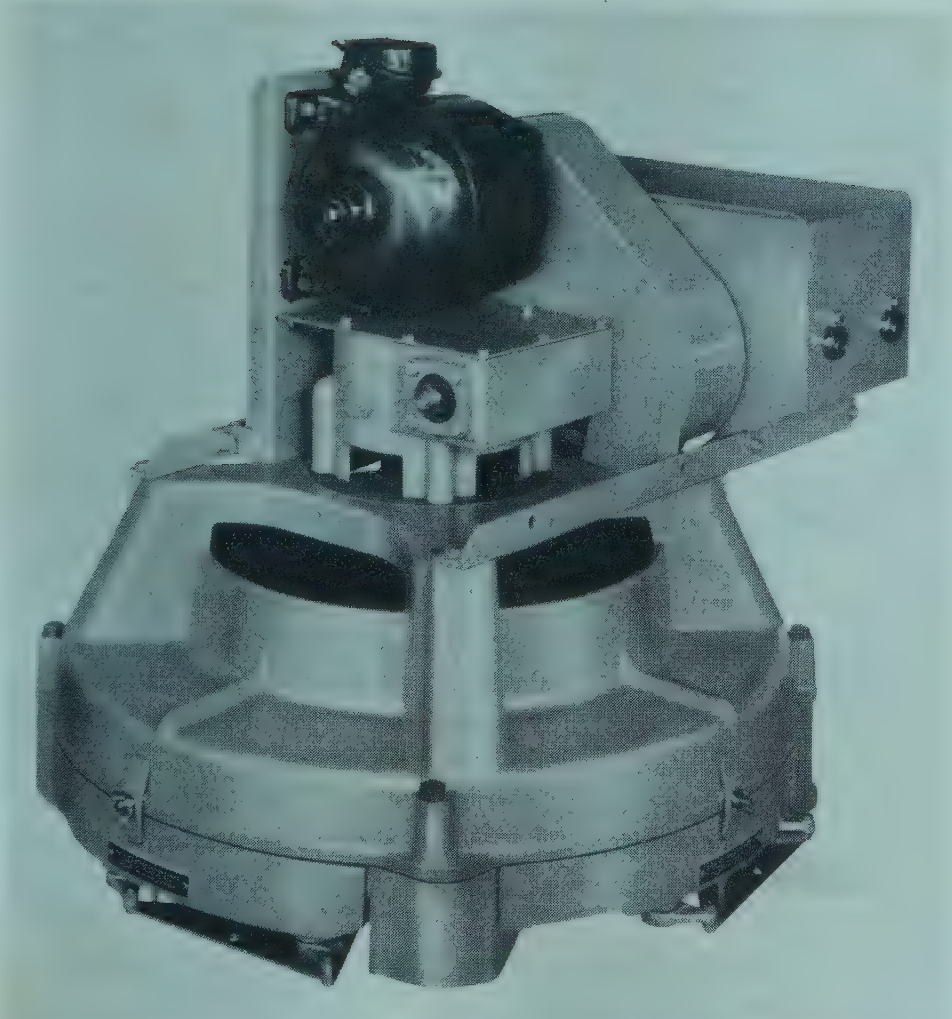
FIG. 53. WEIGHING HOPPER AND PEELER ASSEMBLY

a potato slicing unit. Potatoes on the inspection belt should be trimmed so that all decayed portions are removed. If this operation is not done efficiently it often leads to high per cent pickout of the finished chip on the inspection belt. Trimming losses usually range from almost negligible to approximately ten per cent. It is more economical to remove these defects while the potatoes are still raw rather than wait until they have absorbed oil and lowered cooking efficiency.

Courtesy of J. D. Ferry Co., Inc.

FIG. 54. BUCKET ELEVATOR AND DUAL POTATO SLICING UNIT MOUNTED ON A CONTINUOUS SLICE WASHING MACHINE

Slicing and Washing.—Several slicing arrangements are employed in the industry (see also p. 357). One in common use receives the peeled potatoes from the hopper and discharges them into a dual potato slicing unit mounted on a continuous slice washing machine. The bucket elevator feeding the slicing machine is driven by a remotely controlled variable speed motor so positioned and arranged that the feed of raw product to the process line may be increased or decreased at will by the operator from the operator's console station. Dual slicers are used to handle more adequately the large volume of potatoes that are sliced. Each slicer is separately powered by a manual variable speed gearhead motor. The feed to the dual slicers is so arranged that the slicer cutting



Courtesy of Woodman Co., Inc.

Fig. 55. Potato Slicer Assembly

rotor on either slicer may be changed during operation without interrupting the flow of potatoes to the washing machine. Rotary type slicers are used in most chip plants. The most widely used types have three blades mounted on a circular plate and with two potato pockets in the drum. Thus there are six slices from each potato per revolution. Each pocket may hold three potatoes, therefore, totalling 18 slices per revolution. Some of the newer slicers have four knives and five pockets each capable of holding three potatoes. Thus with each revolution they are capable of producing 60 slices. Slicers are capable of slicing up to 4000 lbs. of potatoes per hour.

Slice thickness ranges from $^1/_{15}$ to $^1/_{30}$ in. Thickness is varied to fit the condition of the potatoes, such as age, turgidity, variety, sugar content and the temperature of fat and cooking time. It is desirable to produce

slices of uniform thickness with smooth surfaces, and with minimum cell fracture or maceration. Slices of uneven thickness are almost impossible to cook properly so that all portions have the desired color and degree of doneness. Slices of rough or torn surfaces may absorb higher amounts of oil during frying.

Slices are washed in rotating reels with additional jets of water under high pressure to remove starch from the cut surfaces and to separate the slivers from the desirable slices. Although in many plants excessive washing occurs, it is necessary that surface starch be removed from the slices to prevent them from adhering to each other during frying. Losses during the slicing and washing operations range from 0.05 to 1.0 per cent of the raw potatoes.

Slice washing equipment consists of a rectangular stainless steel tank with a stainless steel wire mesh cylinder or drum. The drum is rotated within the washing machine tank and is positioned so that potato slices from the slicer assembly discharge into the receiving end of the washing machine drum. The interior construction of the drum provides for propeller action so that water within the tank is moved in the direction of process flow. The slices, as they pass through the drum, are tumbled so that all surfaces of the slices are flushed with water.

The washing machine tank is equipped with suitable overflows and sprays providing for continuous discharge of starch-laden water to the plant sewer system and for constant supply of fresh water to the process line.

Slices are removed from the washing machine tank by means of a stainless steel woven wire mesh conveyor belt and discharged to a second tank commonly referred to as a rinse tank. This tank assembly is similarly equipped with water sprays and starch-water overflows. Slices discharged into the rinse tank are deposited on a second conveyor belt which is used to discharge the potatoes directly to the frying kettle.

Drying Slices.—In the frying process water is removed to the extent that finished chips contain 1.5 to 2 per cent moisture. If surface moisture is removed from the slices before frying it is possible to shorten the frying time and hence to increase capacity of the kettle and also to save fuel used in heating the oil. A number of water removal methods such as the following are in use in some plants: perforated, revolving drum; sponge rubber covered squeeze roller; compressed air and blower fans for blowing off moisture; vibrating mesh belt; centrifugal extraction; and heated air. Rasmussen (1958) found that from 19 to 29 per cent additional moisture was removed from slices which were dried either on a vibrating mesh belt or by sponge rubber covered rollers or by compressed air blowoff.

There is some indication that excessively dried slices may adhere together during frying resulting in soft centered chips.

Treating with Chemicals or Hot Water to Improve Color.—Some plants are equipped to treat potato slices for preventing formation of dark chips during frying. It has been shown earlier in this chapter that dark colored chips result largely from potatoes high in reducing sugar. A number of methods are suggested for treating potato slices to prevent this browning reaction. Water or solutions of chemicals such as the following are used: sodium bisulfite alone or with phosphoric acid and sodium citrate or citric acid; hydrochloric or phosphoric acid; citric acid or sodium citrate; calcium chloride and others. In all of these treatments the water or solutions must be heated to temperatures between 150° and 200°F. After rinsing, slices are placed in the hot solution for one minute or more and then dropped into the frying kettle. The solutions are maintained at the required temperature usually by steam-jacketed tanks. They are equipped with mesh chain belts to carry the slices from one end of the tank to the other during treatment. Equipment for thermostatic control and pH control or control of solution concentration is employed.

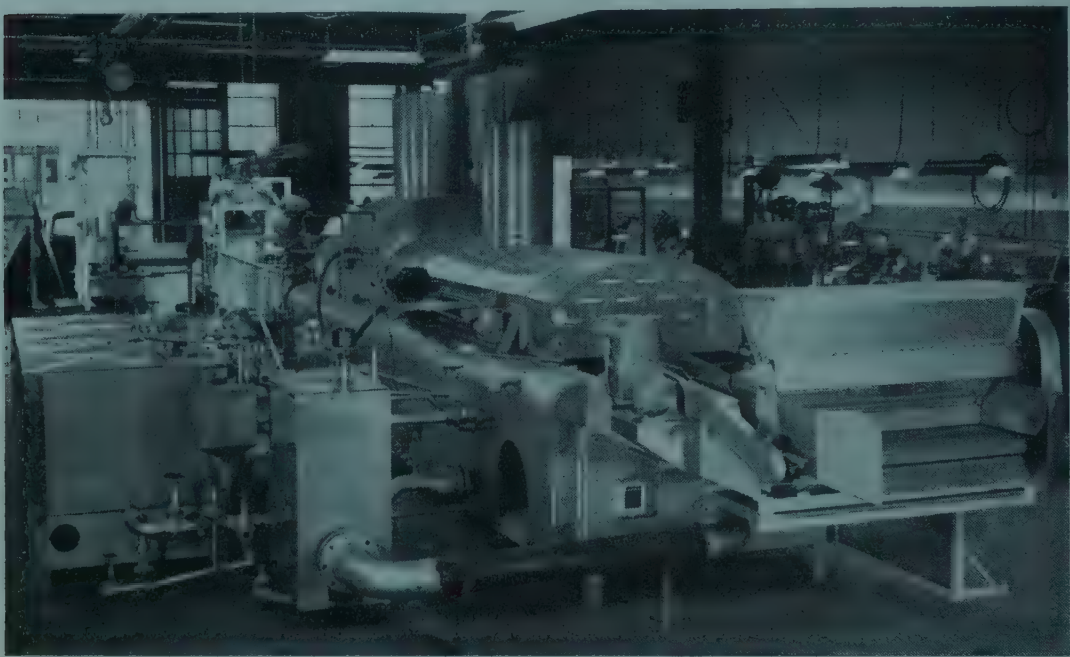
Chip Frying Machinery.—Methods of chip processing may be divided into two categories: the batch method and the continuous method. New installations of continuous processing machinery have replaced as many as 20 batch units, making it possible for one fryer to replace 20 fryers.

Batch Frying Method.—The simplest method of batch frying provides for a slicer to be mounted on a track directly above the frying vessel. This vessel may be either a rectangular, flat bottom tank with burners beneath or may be a tank of the immersion tube type. Batches of potatoes are fed into the slicer and the slices discharged directly into the hot oil. During the frying process the chips are agitated by means of a long-handled basket until, by decision of the operator, they have been sufficiently finished, and are scooped out of the oil with a wire basket and placed on a draining table. The chips are then salted and generally hand packed in containers. Chips produced from this process have a tendency to be hard on the surface because of the presence of surface starch on the slices as they enter the oil.

Some batch processors use the following methods: raw peeled potatoes are sliced into a tub of cold water and allowed to soak. The slices are removed from the water and placed in a centrifuge to remove excess surface water before frying. They are then discharged from baskets into the fryer. Finished chips are removed from the fryer and placed in a centrifuge for the removal of excess surface oil. The chips are hand salted and hand packed. The resultant product from this process differs from the first one in that a certain amount of surface starch has been removed,

resulting in a chip that is more tender. The oil content of chips produced from both processes, however, is relatively high because of the decrease in oil temperature during the frying process when the batch of slices is discharged in a body in the oil.

Continuous Frying Method.—The larger machines manufactured today process from 4000 to 8000 lbs. of raw potatoes per hour and the process is continuous from the discharge of potatoes from either sacks or crates into a receiving hopper until the bagged chips are placed in the shipping carton.



Courtesy of J. D. Ferry Co., Inc.

FIG. 56. DISCHARGE END OF CONTINUOUS FRYING MACHINE WITH SALTER, VEGETABLE OIL STRAINER TANK AND SUPPLY OIL TANK

The frying machine consists of a rectangular, flat bottom vessel, varying in length and width and supported in a structural frame. The kettle is arranged with an inlet manifold so that oil may be introduced at the receiving end, that end into which raw slices are deposited. The chips are removed from the opposite end of the kettle on a conveyor of stainless steel woven wire mesh. The frying oil is continually circulated through the kettle and is removed at the discharge end beneath the chip take-away conveyor. It flows by gravity by means of a piping system to a small tank used as an oil strainer. The oil passes through an interchangeable perforated metal strainer screen or basket contained in this tank. The strainer elements may be changed during the frying process and are designed to remove small suspended particles of potato chips

that may be present in the oil as it discharges from the kettle. A motor driven centrifugal pump is connected to the strainer tank and takes suction from the tank. The pump discharges the oil from the strainer tank to a tubular-type heat exchanger. The heat exchanger may be contained within the framework of the frying machine and positioned directly beneath it. In some machines remotely-fired heating units are used and the oil is pumped into the kettle after being heated elsewhere.

During the frying process oil is taken up by the chips. For this reason a reserve oil tank is positioned adjacent to the kettle and the piping system between the tank and the kettle is arranged with a liquid level control. Constant level of oil in the kettle is maintained by the addition of "make-up" oil from the reserve tank during the frying process. The supply tank also is used to melt hydrogenated shortening to charge the machine prior to frying.

There are several devices in the frying kettle which control the progress of the raw slices through the oil as they are being fried. As the slices enter the oil they pass beneath a slowly rotating cylinder. Slices which tend to float on the surface of the oil are carried into the hot stream of oil entering the kettle, thereby hastening the frying process. The slices pass from this rotating cylinder to a rotating wheel which serves the same purpose and also impedes the flow of slices so that they may be held at the receiving end of the kettle at the point of greatest heat. This makes it possible to "finish fry" the slices at the discharge end of the machine with ease. It is desirable to remove the major portion of the water from the slices before they advance through the kettle to the discharge end of the fryer. A series of perforated baskets known as rakes, suspended on camshafts, are positioned horizontally above the oil and are located at the finishing end of the frying machine. The slices, which have now given up a major portion of their water content, pass from the second wheel and enter the area beneath the rakes. The rakes, which have a series of metal prongs fastened to their lower surface, gently dip the potato slices and turn them as they advance through the final stage of frying. When the chips are discharged from beneath the finishing end of the rakes they pass through a short section of oil in the kettle and are removed from the kettle by the first discharge draining conveyor. The chips are discharged from this conveyor to a second one arranged so that the chips turn as they are transferred from one conveyor to the other. The purpose of this arrangement is to remove oil that may be puddled or held in the large mass of chips. From the second conveyor the chips pass beneath a salter. The product flow is controlled by a short conveyor beneath the salter known as the salting conveyor.

The burner equipment used is arranged with proportioning modulating

temperature controls. This system makes it possible to maintain a constant frying oil temperature of plus or minus two degrees Fahrenheit from the set temperature required. The frying oil circulatory system and burner system are interlocked with a series of safety controls to prevent the operation of the burners should safety conditions not be satisfied either on the burners or in the frying oil system.

A large volume of water vapor is released from the potato slices during the frying process. For this reason the top area of the kettle is covered with a stainless steel hood equipped with one or two steam vent stacks. It has been found that a second stack positioned to receive water vapor from the discharge end of the fryer is desirable. The vents are trapped to eliminate the danger of condensate drip-back from stacks to the frying oil.

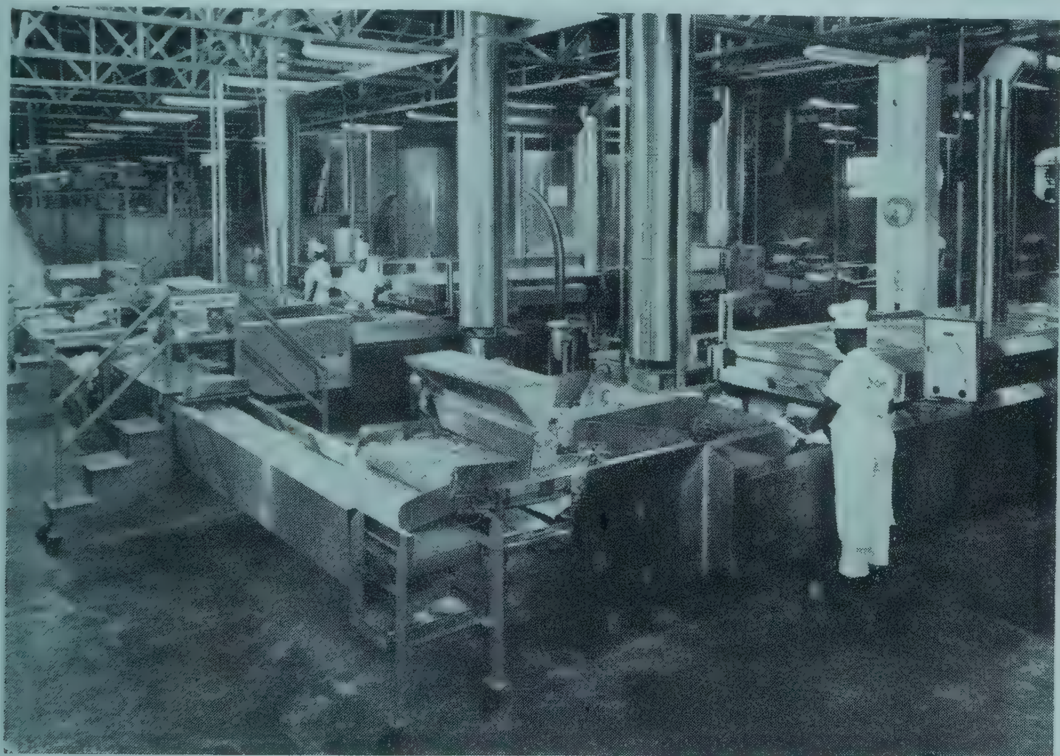
The several controls on the frying machine for the rotary wheels, rakes and conveyors are separately powered and are individually adjustable. This makes it possible for the operator to balance the rate of flow through the machine best suited to the moisture content and frying qualities of the potato used. The rate of feed to the frying machine from the several pieces of slice preparation equipment also is individually controlled making it possible to balance the complete line of product flow through the equipment.

Frying Chips.—Batch fryers are used almost entirely in England and other parts of Europe. In the United States and Canada, however, the smaller operators usually employ this type of cooker as manufactured by Specialties Appliance Corporation and Surf Equipment Company. Most chips on this continent are fried in continuous fryers or kettles such as those manufactured by A. M. Machinery Company, J. D. Ferry Co., Inc., MacBeth Engineering Corporation, Made-Rite Potato Chip Company (Salvo) and Surf Equipment Company.

Continuous frying kettles are heated with a battery of burners utilizing fuel or natural gas. Many of the older type kettles are heated by direct flame under one end of the fryer, the end where the slices are dropped into the oil. The newer type kettles utilize the principle of indirect heating of the oil employing a heat exchange medium such as Aroclor, Dowtherm or other similar material. The heat exchange medium is heated and pumped into pipes that surround or run through the cooking oil and in this way maintain the desired temperatures. The big advantage of this system is that the oil is not overheated at any time or at any point in the kettle, thus reducing breakdown of the oil. It is also claimed that fuel consumption is reduced and that chip quality is better.

Most modern-type kettles are automatically controlled although they are supervised by one operator. The temperature of the oil varies at the heat source end of the kettle from 350° to 375°F. and at the finishing end

from 320° to 345°F. As mentioned earlier in this chapter temperatures are altered to fit the raw product and other conditions prevailing at that time. If it is desired to increase the temperature of the oil the operator slows down the flow of slices into the fryer and if a decrease in oil temperature is wanted the speed of the belt feeding slices into the kettle is increased. The operator does not alter the volume or intensity of the flame for oil temperature control.



Courtesy of Morton Foods

FIG. 57. GENERAL VIEW OF DISCHARGE END OF THREE FRYING MACHINES IN OPERATION

Most kettles, rakes, metal chains, valves, pipes and fittings are made of stainless steel or similar metal to avoid hastening deterioration of the oil. Copper and some other metals greatly hasten the breakdown of fats and oils in storage or during frying.

A number of kinds and types of fats and oils are used in the chip industry. The most extensively used limpid oils in this country are cottonseed, corn and peanut. Solid fats, such as hydrogenated vegetable shortening are used extensively and in some areas almost exclusively. Lightly hydrogenated fats are used to some extent at certain times of the year in a few areas. Very little if any animal fats such as lard are used in the chip industry. It has been shown, however, that lard which has been deodorized,

hydrogenated and stabilized with an acceptable antioxidant is a satisfactory medium for frying potato chips.

Chips fried in hydrogenated vegetable shortening will not become rancid as quickly under the same conditions as those fried in limpid oils. The shelf-life of chips fried in limpid oils can be greatly extended, however, by adding an antioxidant such as butylated hydroxyanisole to the oil or to the salt which is applied to the chips.

Fats and Oils Used and Methods of Handling

Choice of oil, fat or shortening which is used by the processor is based largely on the price differential and the consumer preference for oil- or solid fat-fried chips.

In addition to the use of an antioxidant in the oil or in the salt, rancidity of the oil and chips may be delayed and shelf life extended by employing the following procedures: (1) proper handling of fats and oils in the plant, (2) adequate filtration of the oil, (3) rapid rate of fat turnover, (4) avoidance of prolonged heating of fat without compensating turnover, (5) avoidance of aeration of fat during circulation through equipment such as filters, heat exchangers, frying equipment and holding tanks, (6) avoidance of excessive heat input in an attempt to secure additional frying capacity, (7) avoidance of intensely heated areas in the kettle, (8) avoidance of contamination of oil through drip back from the stack or through feed back of old or spent fat and (9) avoidance of contamination with cleaning and filtering compounds.

Proper Handling of Fats and Oils in the Plant.—In some small operations shortening is scooped out of a drum with a shovel and placed in the fat reservoir of the frying kettle. In others the 400-lb. drums of shortening may be placed in a warming room where the shortening is held in a liquid condition at approximately 120°F. Electric heating elements also may be inserted in the drums of shortening for melting. When melted, the fat may then be emptied or pumped into the storage reservoir or into the kettle. Some processors purchase cubes of shortening which are encased in a liner and a cardboard carton. These may be unwrapped and placed in the reservoir. Limpid oils received in drums may be emptied or pumped into the oil reservoir. Oils received in tank cars or trucks also may be pumped directly to the storage tank. With non-winterized salad oil and hydrogenated fat it is necessary to keep the fat liquid in the storage tanks and lines to the frying kettle. A hot water system is effective for this purpose. Peterson (1956) suggests the following procedures for the handling and care of fats and oils: (a) salad oil or non-winterized cottonseed oil should not be held longer than 30 days in storage tanks, (b) hydrogenated oils, which remain liquid only when heated, should

not be held under heat longer than 15 days before they are used, (c) copper and alloys containing copper should not come in contact with the fat, (d) pipe lines should be kept full of oil at all times. This prevents oxidation of oil in the lines and keeps it in the best condition until it is used, (e) it is better to have several small storage tanks than one large tank thus making it possible to keep more tanks full for longer periods and minimizing the possibility of surface oxidation occurring in the oil during storage, (f) if melted fat is to be held for more than a week, nitrogen blanketing of the oil will help prevent oxidation and flavor change during storage and (g) tank construction should be such that the minimum amount of fat is exposed to the air surface. Tall, narrow tanks are more satisfactory than short, wide tanks.

Adequate Filtration of the Oil.—The most important function of filters is to remove starch grains, chip fragments and other sediment from the oil and keep free fatty acid content to a minimum. Some chippers filter the oil and store it under nitrogen gas when it is not in use.

Three types of filtration processes are used in the industry. In the **gravity or vacuum process** the oil is drained from the fryer into a container such as a drum, with the filter installed in it. The filtered oil is pumped from the bottom of the drum to the storage container. Filters sometimes consist only of a 200 or 250 mesh screen. Others employ paper filters with Fuller's earth or similar adsorbent to clarify the liquid during filtering. These materials such as Fuller's earth remove particles from the oil above three microns in size.

Another type of filtration employs a **filter press** which can be connected to the fryer as part of a continuous process or for batch filtration. In this process used oil is pumped from the fryer and forced under pressure through the press. Some presses contain a series of wire mesh filter media, others utilize fabric or paper media for finer filtering. A screen filter usually is used with paper or fabric filters to eliminate coarse particles and to increase the volume of oil through the filter press.

Centrifugal clarification of fats and oils also is used in this industry. When the used fat is rotated at sufficient velocity, centrifugal force causes the solids to adhere to the vertical sides of the container from which they may be removed and discarded (Foster 1957). Ronzone (1955) reported that on test runs with centrifugals in actual production the smoke point of the oil was raised approximately 15°F. and by continuous clarification at the rate of about 600 gal. per hour the free fatty acid was stabilized at approximately 0.3 per cent. The appearance of potato chips was greatly improved with centrifuge filtration of the oil. Dark spots were eliminated and a more uniform chip color was maintained. A strainer with 100-mesh

screen in front of the centrifuge to remove most of the solids increases the cleaning cycle to once every 6 to 8 hours.

Rapid Rate of Fat Turnover.—Continuous heating of oil at the high temperatures necessary for frying potato chips results in several types of breakdown of the oil. This deterioration of the oil results in accumulation of substances which affect flavor and stability or shelf life of the chips. One of the best methods of keeping this deterioration to a minimum is to have rapid turnover of the oil in the kettle. It is well in many instances to reduce the capacity or size of the cooking kettle and to fry for as long periods as possible to insure rapid rate of turnover of the fat.

Avoidance of Prolonged Heating of Fat Without Compensating Turnover.—Experimental evidence as well as experience of processors has shown that oil breakdown is greatly reduced when fresh oil is continuously added to the kettle to supplant that absorbed by the chips. It is well to maintain the oil level in the kettle at the same point that prevailed at the start of the frying operations.

Avoidance of Aeration of Fat during Circulation Through Equipment.—Aeration of fat results in its rapid deterioration by oxidation. If fat is allowed to cascade from one area to another or from pipes into filters, frying equipment, heat exchangers or holding tanks, aeration is greatly increased and rapid breakdown occurs. It is best to have the oil enter another container near the bottom of the receptacle so that it is not exposed to the air. It also is recommended that the surface of the oil in the kettle exposed to air and oxidation be reduced by placing a metal float on the surface of the oil between frying operations. In this way free fatty acid of the fat is maintained at a lower level, rate of darkening of the fat is decreased and the A.O.M. value in hours is kept at a higher figure..

Avoidance of Excessive Heat Input.—In an attempt to attain additional frying capacity some operators raise the temperature of the frying fat. Temperature of frying fats should never be raised above 385°F. and it would be best to keep it lower than this. The higher temperatures result in a more rapid rate of breakdown of the fat and thus affect the flavor and shelf-life of the chips.

Avoidance of Intensely Heated Areas in the Kettle.—Localized overheating of fats in certain areas of the kettle is undesirable because of the rapid breakdown of the fat. In direct-fired kettles this is more likely to occur than in those utilizing heat exchangers. Often the temperature of the oil near the bottom of the kettle above the flame is much higher than that of the oil in other parts of the fryer. This results in more rapid breakdown of the oil and is reflected in the keeping quality of the chips.

Avoidance of Contamination from Used Oil.—Contamination of fresh oil in the fryer may occur by allowing condensed oil to drip back into the

kettle from the exhaust stack. Fats may also be contaminated by feeding old or spent oil back into the frying kettle. During frying of potato chips a thin layer of oil encases each steam particle as it rises from the kettle and is drawn up the exhaust stack. As the steam and oil condense some of the oil liquifies and runs back down the stack and may drip into the kettle. Analysis of fat taken from the exhaust condensate of 16 potato chip plants showed that free fatty acids ranged from 0.52 to 19.6 per cent and iodine value from 10.1 to 121.8 (Schroeder 1958).

Experiments have shown that as little as 12 ounces of these drippings per 100 lbs. of fat greatly accelerate the rate of foam development, rate of oil color development and the rate of free fatty acid formation (Carlin *et al.* 1954). This often results in poorly flavored chips of relatively short shelf life. Sometimes operators may wish to use old or used oil by adding it in small quantities to fresh oil in the fryer. This practice should be discouraged. Such added oil results in contamination of the fresh oil, causes rapid breakdown of the oil and shortens the shelf life of the chips.

Avoidance of Contamination with Cleaning and Filtering Compounds.—It is well at the end of each days operation to drain the oil from the fryer and to clean it with steam. It is advisable also to clean the frying equipment occasionally with soap or alkaline cleansers. This should be followed with thorough rinsing since traces of soaps or alkaline cleansers can react with the oil and cause it to deteriorate. Fats contaminated with soaps are greatly increased in their rate of discoloration during the frying process.

Oil Losses Through the Stack.—Chip processors have been concerned for a long time about the material removed from the fryer through the exhaust stack. Some processors report fat disappearance of 3 to 5 per cent although it is doubtful that much of this loss is through the stack. Equipment manufacturers have installed baffling systems in exhaust stacks to eliminate this drip back. Some processors have elaborate devices to reduce this problem and to prevent fat particles from escaping to the surrounding area. There are indications that strong drafts will increase the amount of fat carried up the exhaust stack (Schroeder 1958).

Salting Chips and Adding Flavoring Materials

As the chips are removed from the fryer they receive an application of salt. The salter consists of a hopper with a grooved roll positioned along an opening provided at the base of the hopper. A blade mounted within the hopper and adjustable is used to control the rate of salt flow from the hopper to the grooved roll immediately beneath it. This roll carries salt in each of the grooves as it slowly rotates beneath the hopper. A brush is

Courtesy of Morton Foods

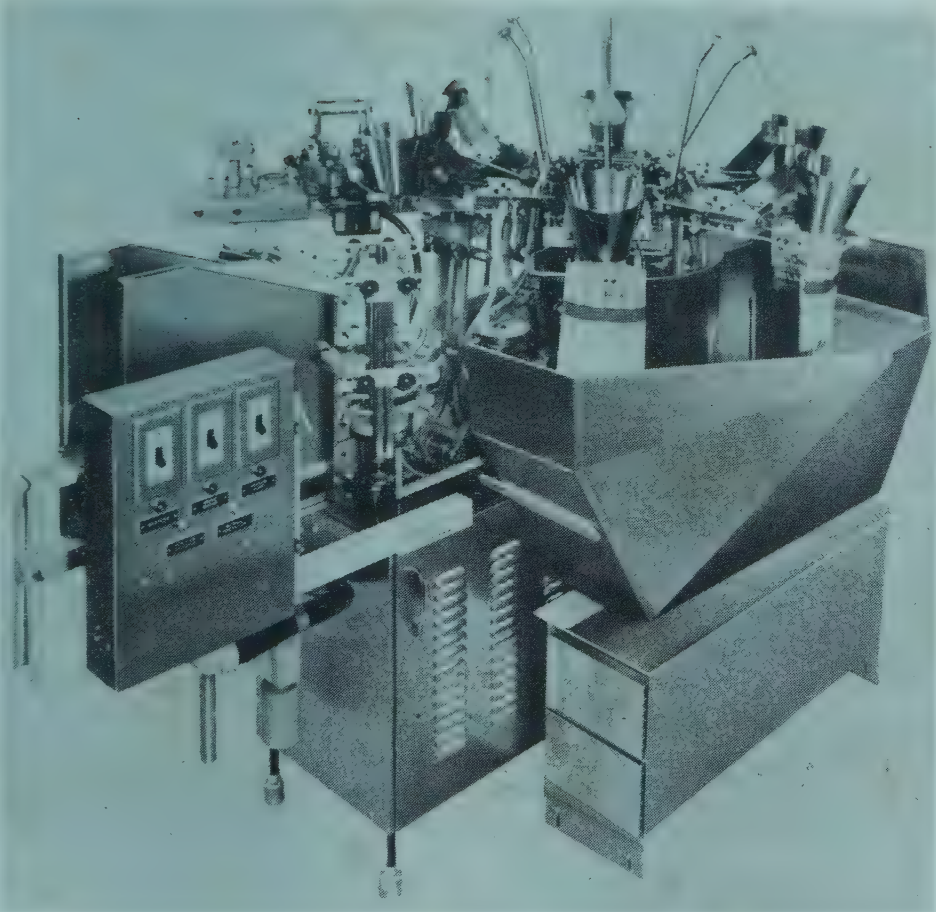
Fig. 58. General View of Packaging Area in a Modern Chip Plant

driven in counter rotation to the grooved roll which removes the salt from the grooves of the salter roll and discharges it over the chips passing beneath. A uniform application of 1.5 to 2 lbs. of salt is applied to each 100 lbs. of chips. Special grades of fine crystal sodium chloride are used by most chippers. Antioxidants may be uniformly mixed with the salt and applied in the same manner.

Monosodium glutamate intensifies the flavor of potato chips. If this ingredient is to be used it should be mixed with the salt and applied in the same operation. One part monosodium glutamate to 10 parts salt provides a satisfactory concentration. Barbecue, hickory smoke and cheese or other flavoring materials are added to some chips. This usually is done by dusting or spraying the flavor materials on the chips in a rotating drum which distributes the flavor materials uniformly on the chips (see also p. 255).

Inspecting and Packaging Chips

From the salter the chips drop onto a belt which is used both for inspecting and for cooling the chips. Low grade, off-color chips are



Courtesy of Woodman Co., Inc.

FIG. 59. AUTOMATIC BAG FILLER AND SEALER PICKS UP BAG, OPENS IT, FILLS IT, SETTLES THE CHIPS, CLOSES AND SEALS IT

removed from the belt and discarded. It is best to allow chips to cool before packaging. This may be done by conveying them on belts to the packaging machinery or they may be placed in large metal containers and set aside to cool.

Chips are fed from the cans or from a belt into hoppers which, in turn, supply the weighing and packaging machines. Chips are weighed automatically in most large plants and dropped into the containers for closure. Flexible packages of many sizes are used holding from less than one ounce to one pound. Flexible packaging materials largely are waxed glassine, cellophane and some aluminum foil. Bags may be of single or double wall depending upon thickness of the stock and time of year or area where the chips are to be marketed. Some packages are stapled but most are heat sealed with automatic machinery. A number of processors package chips in plain waxed glassine which is enclosed with a rigid paper carton with waxed and printed overwrap. Some twin-packs also are packaged with

two waxed glassine or cellophane packages overwrapped with the same material or enclosed in a carton. A number of plants purchase the packaging material as roll stock and fabricate their own bags as they are needed for filling. Sealed, filled bags are then cased in cardboard cartons and are ready for delivery.

Slip-top metal cans of various sizes also are used extensively in some areas as chip containers.

It is important to maintain proper moisture content of stored empty bags. If cellophane increases its moisture content it is difficult to heat seal after filling. If it loses moisture it becomes brittle and is likely to crack or break. When the correct moisture content is attained it may be retained by packing the bags in polyethylene-lined cartons. Exposure of packages and packaging materials such as glassine and cellophane to low temperatures should be avoided as this renders them more subject to cracking and breaking.

Opaque or transparent packages of chips should not be exposed to direct sunlight. Light rays hasten deterioration of the fat in chips and decrease their shelf life. The infrared or heat energy from the sun also increases the temperature of the chips in the package and this hastens development of rancidity and staleness. Deterioration of chips caused by light is directly proportional to the light transmission of the packaging material and as light transmission increases the internal temperature of potato chip packages rises, (DuVernay 1958). The air temperature inside black coated metal cans also is higher than that in white or silver coated cans.

Waste Disposal

In many areas waste disposal is a serious problem. Chip plants located in small cities or villages often are discouraged from using the municipal sewage system for disposal of their waste because of the large amount of organic matter. It also needs considerable attention in rural areas where the processor has his own water supply but no adequate sewage system. Stream pollution often occurs under such conditions. Wet waste such as potato peels and trimmings may be ground in a chain-belt or other type of grinder. Water may be discharged into the grinder so that the comminuted waste is fluidized for discharge into the municipal sewage system. Coarse material often is screened out before grinding and it is disposed of as garbage or for stock feed.

In a study which was made of waste from potato chip plants to determine unit production pollution factor, Porges (1952) found that the pollution equivalent of potato peeling waste from 1000 lbs. of potatoes processed is 33 based on biochemical oxygen demand (B.O.D.) and 66 based on suspended solids.

POTATO CHIP CONFECTIONS

Research workers at the Eastern Utilization Research and Development Division, U.S. Dept. Agr. (Treadway *et al.* 1958) have developed a potato chip product known as a chip bar (see also 446 to 449). Bars are made of crushed potato chips, compressed and cut into three-inch strips about five-eights inch thick and one inch wide. They have potato chip flavor and the crunchiness of chips yet require only about five per cent of the storage and shipping space of chips. They are a concentrated source of energy and may prove to be adaptable to the Armed Forces as well as civilian consumption.

Bars canned in air or nitrogen remained fresh when stored up to six months at room temperature and some retained their quality for six months at 100°F. Packing bars in nitrogen made it possible to store bars in edible condition for as long as one year.

Other potato chip confections have been made by Townsley and Dixon (1952). They dusted chips with prepared powdered and flavored candies. They also coated chips with chocolate. None of these chip confections, however, is produced commercially.

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Frozen French Fries and Other Frozen Potato Products

GROWTH OF THE INDUSTRY

The frozen potato products industry is reported to have begun in 1945 with the commercial freezing of French fries by the Snow Flake Canning Co., a subsidiary of H. C. Baxter and Bros., Brunswick, Maine (Anon. 1954A). Since then, production of frozen French fries and other frozen potato products has increased steadily from the initial volume of about $3\frac{1}{2}$ million lbs. to a total of over 219 million lbs. during the 1956–57 crop year. As shown in Table 35 production more than doubled during the short space of two years from 1955 to 1957 and increased more than eight times since 1951. Per capita consumption of frozen potato products is second only to peas among all frozen vegetables.

About 9 million bushels of potatoes were used from the 1956 crop for processing into frozen potato products. This represents 13.6 per cent of all potatoes used in food processing, excluding pre-peeled potatoes, but corresponds to less than 3 per cent of all potatoes (both fresh and processed) used for food. A comparison of the retail value of various potato products (Table 36) shows that frozen potato products (reported as frozen French fries) account for slightly over five per cent of the total value of fresh and processed potatoes.

Until recently, institutional outlets, as compared with the retail trade, have received only a very small share of the market for frozen potato products. In 1953, for example, only about six per cent of the total pack went to restaurants and other institutional or bulk users. This figure increased to 13.4 per cent in 1954, to 26.9 per cent in 1955, to 40 per cent in 1956, and to 43.3 per cent in 1957. The J. R. Simplot Company, Caldwell, Idaho, has been credited as being the first packer to develop a frozen potato product, namely par-fried or oil-blanched French fries, for the institutional market.

Most of the principal producers of frozen potato products (shown in Fig. 60) are located in the Pacific Northwest and in the Northeastern part

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TABLE 35

PACK OF FROZEN POTATO PRODUCTS[1]
1950–1951 through 1956–1957

	12 Months Ending in Summer of 1951	12 Months Ending in Summer of 1952	12 Months Ending in Summer of 1953	12 Months Ending in Summer of 1954	12 Months Ending in Summer of 1955	12 Months Ending in Summer of 1956	12 Months Ending in Summer of 1957
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
French fries:							
Plain	23,872,918	32,316,742	52,839,438	61,742,429	83,405,741	133,256,278	190,340,326
Crinkle cut	...	...	...	250,000	500,000	750,000	4,579,418
Diced	266,384	960,028	4,643,820	4,409,087	1,085,331	2,178,521	1,348,672
Patties	...	...	...	2,473,719	11,359,227	17,158,194	13,417,609
Mashed or whipped	877,104	844,536	3,368,048	2,961,243	2,050,543	3,664,039	3,792,163
Puffs	...	...	...	44,861	852,512	1,064,610	1,523,895
Others	...	...	101,075	547,186	951,385	3,304,737	4,058,253
Total	25,016,406	34,121,306	60,952,381	72,428,525	100,204,739	161,376,379	219,060,336

TABLE 36

ESTIMATE OF THE RETAIL VALUE OF THE 1956 POTATO CROP SOLD FOR FOOD[1]

Product	Value
Potatoes sold fresh	$ 810,800,000[2]
Potato chips	472,000,000[3]
Frozen French Fries	73,000,000[4]
Dehydrated potatoes	15,000,000[5]
Canned potatoes	15,600,000[6]
Hash, stews, soups	3,200,000[7]
Potato flour	3,000,000[8]
Total retail value	$1,382,600,000

[1] Information supplied by the National Potato Council.
[2] Estimated 228 million bushels sold fresh at an average price of 6.5 cents per lb.
[3] Estimated 45 million bushels used for the processing of 675,000,000 lbs. of potato chips at 70 cents per lb.
[4] Estimated 9 million bushels used to process 243,000,000 lbs. valued at 30 cents per lb.
[5] 60,000,000 lbs. estimated 1/2 sold at 30 cents per lb., 1/2 at 20 cents per lb.
[6] 1,400,000 bushels of which 1 1/2 lbs. are estimated to be equivalent to 1 lb. drained weight at 10 cents per lb.
[7] 800,000 bushels at same basis as for canned products.
[8] 30,000,000 lbs. at 10 cents per lb.

TABLE 37

LIST OF FROZEN POTATO PRODUCTS
Packed individually and/or as ingredients of pre-cooked frozen dinners

French fries	Baked
Regular cuts	Shredded
Crinkle cuts	Boiled
Retail pack	Rissole
Institutional pack (par-fries)	Au Gratin
Patties	Creamed
Round	Scalloped
Rectangular	Delmonico
Onion flavored	Roasted
Mashed	Cottage Fried
Riced	Knishes
Whipped	Cakes
Cuts for mashing	Cream of Potato Soup
Shredded for mashing	
Dehydrofrozen or concentrated	
Dice	
Onion flavored	
Hash brown	
Puffs	
Baked stuffed	

[1] Information supplied by the Frozen Potato Products Institute, Chicago, Ill.

of the United States. Idaho produces the greatest volume of potato products with Maine second in importance.

The pack of frozen French-fried potatoes produced in other countries is only a small fraction of that produced in this country. Canadian production is increasing, however, and reached a total of 3.2 million lbs. in 1956 as compared with 1.9 million lbs. in 1955 (Paige 1957).

A number of frozen by-products or co-products, such as patties, puffs, hash-brown and mashed potatoes, has become closely associated with the

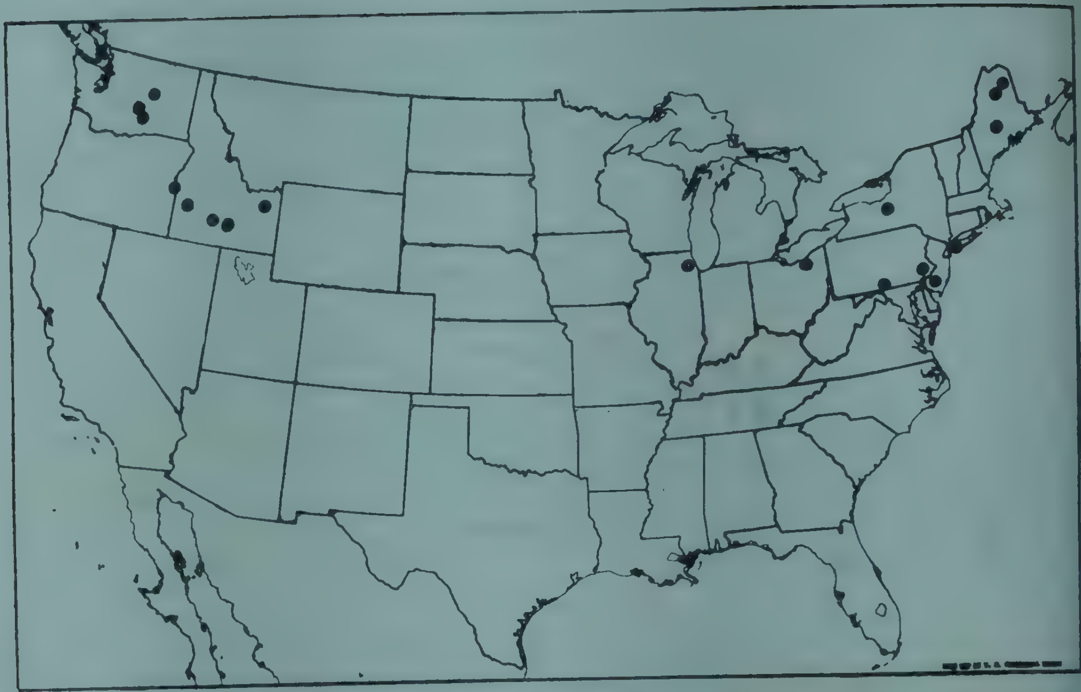


FIG. 60. LOCATION OF PRODUCERS OF FROZEN POTATO PRODUCTS

production of frozen French fries. These products not only serve a very important purpose in utilizing slivers and short pieces or nubbins of potato that would otherwise be wasted in the French fry cutting operations but have also provided diversity and have contributed to the widespread popularity of frozen potato products. However, French fries are the most important of the various frozen products and comprise over 85 per cent of the total volume.

The considerable variety of frozen potato products that have become available are listed in Table 37. New frozen products are being introduced from time to time. Among the more recent is a shredded and extruded deep fat fried product. Another is dehydrofrozen mashed potato. The latter is partially dehydrated before freezing to save shipping and container costs.

The Frozen Potato Products Institute was organized in Chicago, Illinois, in 1957 for the purpose of expanding the sales and consumption of frozen potato products. It represents the entire frozen potato products industry and has embarked upon an intensive public relations program to achieve its objectives. In addition to its promotional and educational activities it also originates pack and pack movement statistics.

CONVENIENCE AND QUALITY OF FROZEN POTATO PRODUCTS

French-fried potatoes are becoming increasingly popular. The frozen product is a decided convenience for the consumer, since it needs only to

be removed from the package and heated in an oven before serving. To prepare fresh French fries at home necessitates washing the potato, peeling, cutting it into strips and frying at the correct temperature in a sizable volume of oil. Many homes do not have deep fat fryers and at best the frying oil is difficult to maintain in good condition unless it is in more or less constant use and is frequently replenished. Some consumers regard the frozen French fries as somewhat inferior in texture and flavor when prepared for serving by heating in an oven as compared with those which they are able to produce from freshly prepared potatoes. However, many housewives do not have access to or are unable to select potatoes that are high in solids and that will consistently make good French fries. Fresh potatoes are variable in quality depending on variety, storage conditions prior to use and other factors and may or may not be well suited for French frying. Unfortunately, the outer appearance cannot be relied upon as an indication of frying quality. Consequently, there will be times when the home-made French fries may be soggy, or limp, excessively greasy, too dark in color, or have a scorched taste. The processor of frozen French fries not only provides convenience but also a product which is dependable in quality regardless of the season of the year in which it is purchased. The processing plant is usually located in or near a sizable potato growing area from which the processor can select raw material best suited for his particular product or products. Also, he can manufacture his products in large volume from relatively uniform lots of potatoes and make them available during seasons when fresh market potatoes may be low in quality, high in price, or possibly unavailable. Elimination of peeling and trimming waste and other reductions in weight at the processing plant effect savings in cost of shipping potatoes to consuming centers.

Advantages for institutional users of frozen potato products include (1) knowledge of exact cost, number of servings and cost per portion; (2) greater flexibility in meal preparation; (3) simplification of storage and inventory control; (4) receiving with a minimum of kitchen disruption; (5) uniform quality from one season to another; and (6) reduced labor and time in preparation for serving. Some of these same advantages apply as well to the home user but convenience of preparation is undoubtedly the major factor involved in the housewife's choice of frozen potato products as compared with the use of fresh potatoes.

Frozen French fries (par-fries) packed for the restaurant and other institutional trade are prepared for serving by finish frying in deep fat. This gives a higher quality product than is obtained by oven heating of frozen French fries packed for the home consumer. Common practice in preparing French fries from fresh potatoes in the restaurant is to fry them in deep fat in two stages. Use of the frozen par-fries eliminates the first

stage of frying and requires only the short second stage (approx. one minute) to prepare for serving. French fries prepared in this manner have usually been observed to be more crisp and to hold their crispness longer after preparation when compared with those prepared directly from fresh potatoes by the institutional user.

PROCESSING QUALITY OF POTATOES USED FOR FRENCH FRYING

One of the most important problems in the production of frozen potato products is the selection and procurement of suitable raw tuber stock, particularly since processing is usually spread over 9 or 10 months of the year. Most processors suspend operations during the summer when the stored late-crop potatoes from the preceding year are no longer in dependable supply or do not have satisfactory processing qualities.

No entirely adequate standards of suitability of potatoes for processing have been established which will at all times assure the highest quality of frozen French fries. Variety of potato is considered to be the most important single factor influencing processing quality and those varieties which are consistently high in solids content have generally proven best for processing. Compositional characteristics of the same variety will often vary from one producing area to another and even from field to field in the same area. These variations have been ascribed to differences in climate, cultural practices, soil conditions and other factors. Values for specific gravity (solids content) and reducing-sugar content and results of frying tests of any given lot of potatoes are regarded as the most reliable guides in the selection of raw material for processing.

Alexander *et al.* (1949) pointed out the desirability of selecting mealy (high specific gravity) potatoes rather than non-mealy (low specific gravity) ones for French frying based on their experience with Katahdin potatoes. It was also observed that the texture as well as color was significantly improved by progressive conditioning (desugaring) of the potatoes which had been held in low temperature storage. The more mealy the potatoes, the more rapidly they responded to conditioning treatment and the better the edible quality of the French fries.

Smith (1957) lists Irish Cobbler, Russet Burbank, Russet Rural, Sebago, Kennebec and Katahdin as being among the best varieties for French frying. Other varieties such as Green Mountain often accumulate such high concentrations of reducing sugars during storage that they yield dark-colored and unattractive French fries and cannot readily be conditioned to attain satisfactory levels of sugar content.

The French frying qualities of potatoes as influenced by cooking method, storage conditions and specific gravity were investigated in considerable detail by Kirkpatrick *et al.* (1956). In their work, criteria used

to evaluate palatability of French fries prepared by a two-stage frying method, included uniformity of browning, lack of oiliness, tenderness, crispness, mealiness, and flavor. Taste panels were used for scoring. Tenderness was also measured by a shear test. Potatoes of high specific gravity produced fries which were more crisp, more mealy and less oily than did potatoes of low gravity. Flavor scores were also higher in some instances with potatoes of high specific gravity. When the mean scores for

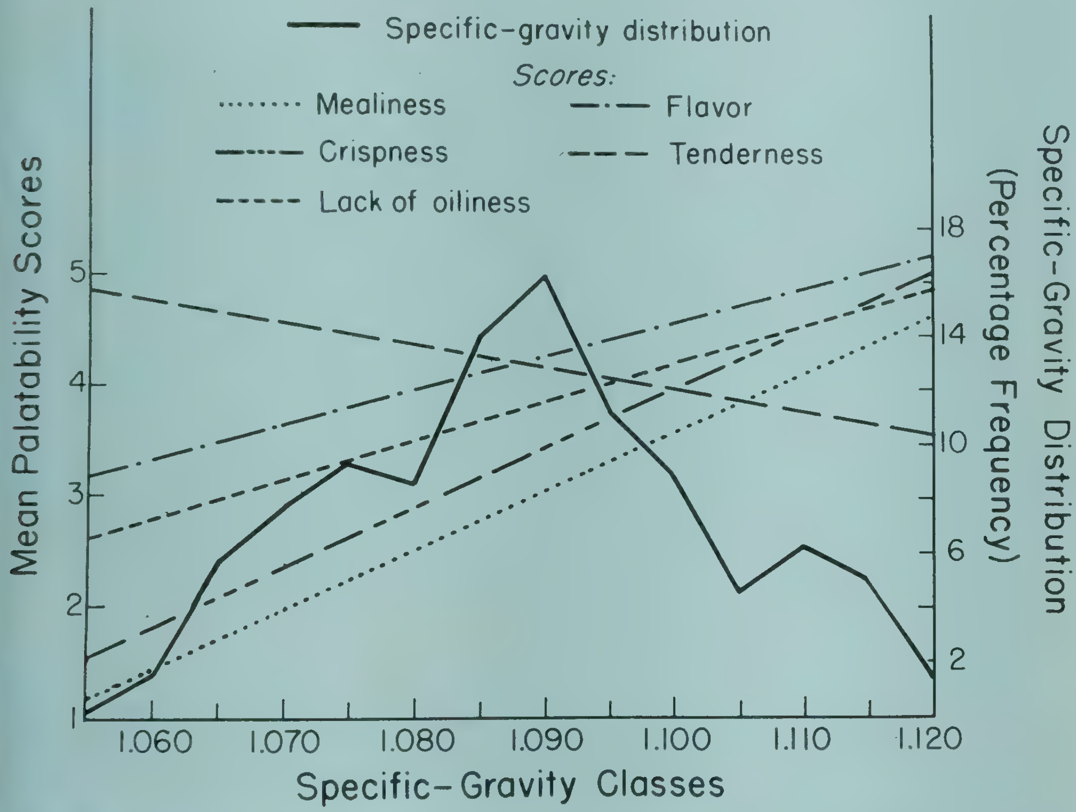


FIG. 61. SPECIFIC GRAVITY DISTRIBUTION OF POTATOES FROM SIX VARIETY-LOCATIONS, 1952 CROP

Regression lines show mean scores for various characteristics on specific gravity (5 represents the optimum score and 1 the poorest for each quality attribute).

the above-mentioned criteria of quality, collectively referred to as "palatability," were averaged for four potato varieties (1952 harvest) from different areas (Chippewa, Katahdin, and Irish Cobbler from Maine; Irish Cobbler from North Dakota; Katahdin from Colorado; and Russet Burbank from Washington) it was observed that palatability increased as specific gravity increased (see Fig. 61). Tenderness, however, showed a slight but significant decrease (increase in toughness) as specific gravity increased and this was the only quality factor negatively correlated with

specific gravity. No significant differences in tenderness were found among the different varieties of potatoes tested.

INFLUENCE OF STORAGE CONDITIONS

Storage temperatures of 50° to 55°F. are generally regarded as more conducive to maintaining good tuber quality for French frying than are lower temperatures sometimes used. Terman *et al.* (1950) found that French fries prepared from potatoes stored for two or three months at 50° to 60°F. had better texture, flavor, and color than those prepared from potatoes stored below 50°F. Temperatures appreciably below 50°F. have been found by many investigators to result in conversion of part of the starch to reducing sugars which causes the French fries to be too dark in color. However, potatoes are stored at 40°F. or lower in many commercial storage cellars to minimize sprouting, withering and spoilage. Under these conditions, reducing sugars usually reach a high concentration and the potatoes must be conditioned (held at 70°F. or higher for two or three weeks) to lower the sugar content. Different varieties of potatoes differ in their ability to form reducing sugars in low-temperature storage and, as already pointed out, some varieties accumulate such high concentrations that they cannot be conditioned satisfactorily. Growing area also influences the tendency to accumulate reducing sugars and a processor must consider this as well as the varietal factor in selecting his raw material. Pentzer (1950) reported that some potatoes fail to yield a good product after conditioning even though the reducing sugar drops to a relatively low level.

Treatment of potatoes with chemicals that inhibit sprouting will permit storage at 50° to 55°F. and may thereby solve the problem of reducing sugar build-up since processing qualities remain relatively unchanged at these temperatures.

Practices recommended for the storage and conditioning of potatoes for chip manufacture are also applicable for frozen French fry production. However, the reducing sugar content of potatoes destined for French frying is somewhat less critical since the frying is not carried to the same degree of completeness as in the case with chips. In addition, blanching conditions can be adjusted to minimize the effect of variations in reducing sugar content.

PREPARATION OF POTATOES FOR FRYING

Washing, Peeling, and Related Preparations

Potatoes are usually peeled with lye or with steam by processors of frozen potato products (see p. 210 and 215). Peeling losses by abrasion

peeling are usually so high as to make this method uneconomical. Procedures for washing and peel removal with differet types of equipment are similar to those described elsewhere in this book.

Trimming, Sorting, and Cutting

Peeled potatoes are conveyed over trimming and inspection belts in preparation for processing. Unpeeled portions, bruises, black spots, rotten parts, etc. must be removed by trimming. Sun or wind-burned po-

Courtesy of J. R. Simplot Co.

FIG. 62. PEELED AND TRIMMED POTATOES DESTINED FOR MANUFACTURE INTO FROZEN FRENCH FRIES AND OTHER FROZEN POTATO PRODUCTS

tatoes and those with serious defects are diverted from the processing lines. In some plants the largest potatoes (four inches or over in thickness) are cut in half lengthwise to facilitate cutting into French-fry strips. Potatoes less than $1^1/_4$ in. in size are usually removed from the French-fry line for processing as potato patties, hash brown stock, or mashed potatoes.

Holding tanks used as surge hoppers to regulate the flow of peeled and trimmed potatoes to the strip cutters are filled with water to reduce sur-

face oxidation or discoloration. The strip cutters are specifically designed for high speed operation in producing French-fry cuts. This equipment should orient the potatoes along the long axis, or as nearly so as possible, in order to obtain the greatest yield of long cuts. The size of French-fry cut can be varied, but strips $^3/_8$ or $^1/_2$ in. square in cross section are the most popular. Cuts of other sizes are produced for special orders.

Slivers and short pieces or nubbins must be separated from the product following cutting into French fries. A rotating reel or a screen shaker with slots spaced to eliminate the slivers is one type of equipment used for this purpose. A nubbin eliminator usually follows the sliver eliminator in the processing line. One type of equipment consists of a rotating drum fitted with cups in the shell of the drum. The diameter of each cup is such as to accommodate the length of potato strips to be separated from the product as it passes through the drum. As the nubbins drop into the cups they are lifted to the upper position of the rotating drum and dumped on a belt, which carries them to a co-product line. The long cuts remain in the drum until they have traversed its entire length. Another type of nubbin eliminator consists of a vibrating screen having openings of the proper dimensions through which the nubbins fall as the potatoes move across the screen. Following the sliver and nubbin or short-piece eliminators, some operators have a short inspection line. At this point any remaining small pieces and discolored or otherwise defective strips are removed.

The yield of French-fry cuts is governed by peeling, trimming, and cutting losses. These losses will vary with size and grade of potatoes used, peeling method, and other factors. Peeling and trimming losses usually fall within the range of 15 to 40 per cent. Removal of slivers and nubbins may involve a loss of ten per cent in addition to peeling and trimming losses. The overall yield of raw French-fry cuts can thus be expected to fall within the range of 50 to 75 per cent of the weight of potatoes processed. A further reduction in weight occurs during frying due to removal of moisture which more than offsets the weight of fat absorbed. The final yield of finished French fries obtained from 100 lbs. of potatoes is in the range of about 30 to 45 lbs.

Blanching

The French-fry strips are usually water blanched prior to frying. Advantages of blanching include (a) more uniform color of fried products, (b) reduction of fat absorption through gelatinization of the surface layer of starch, (c) reduced frying time since the potato is partially cooked by blanching, and (d) improved texture of final product.

Blanching has a leaching effect on the sugars and serves to even out

variations of sugar concentrations at or near the surfaces of the French-fry strips. This gives a lighter and more uniform color on frying. Otherwise, portions of the surface tissues which are higher in sugar content than surrounding ones become correspondingly darker in color and cause a mottled and undesirable appearance in the final product. However, the leaching effect of blanching may also result in loss of desirable flavor constituents from the potato. This may be minimized by allowing the blanch water to build up a concentration of extracted soluble constituents so as to restore some of the soluble material extracted by passage of the potatoes through the blancher.

Blanching does not eliminate the need for conditioning the potatoes to lower the over-all reducing sugar content when this is too high for French fries of satisfactory color. However, adjustments can be made in time and temperature of blanching to minimize differences in sugar levels in different lots of potatoes since considerable variation is encountered from time to time in the raw material. Gould (1954) pointed out the necessity for careful control of both blanching and frying conditions in order to obtain products of optimum quality.

Variations in time or temperature of blanching, or both, are made on the basis of experience by processors to adjust to variations in the raw material. Common practice is to operate two blanchers in series for greater flexibility and more effective control of product color. The first blancher may be used, for example, in the manner described above while the second may contain a dilute sugar solution and be used as an aid in adjusting the surface sugar concentration to a level which gives the best color on frying. Under some conditions it will prove desirable to use both blanchers for their maximum leaching effects to avoid the product being too dark in color. Two blanchers may also be used to increase the capacity of the plant.

After blanching, provision is usually made to remove excess moisture from the strips in order to reduce the load on the fryer and to minimize the rate of hydrolytic breakdown of the fat. Benes *et al.* (1941) have pointed out that the lower the moisture in the potato, the less will be the time required for frying and consequently the lower the oil content of the product. Free surface moisture, if left in contact with the strips for any length of time, is also undesirable because this tends to soften the pieces. The surface moisture is removed in part by the use of dewatering screens and the strips may be dried further by blowing warm air over them. Jones (1953) described a specially designed unit for drying which follows the dewatering screen. This consists of three horizontal belts placed one above the other. The potato strips are caused to cascade from the first

to the second belt and then to the third belt while high velocity air is forced through the potatoes.

FRYING

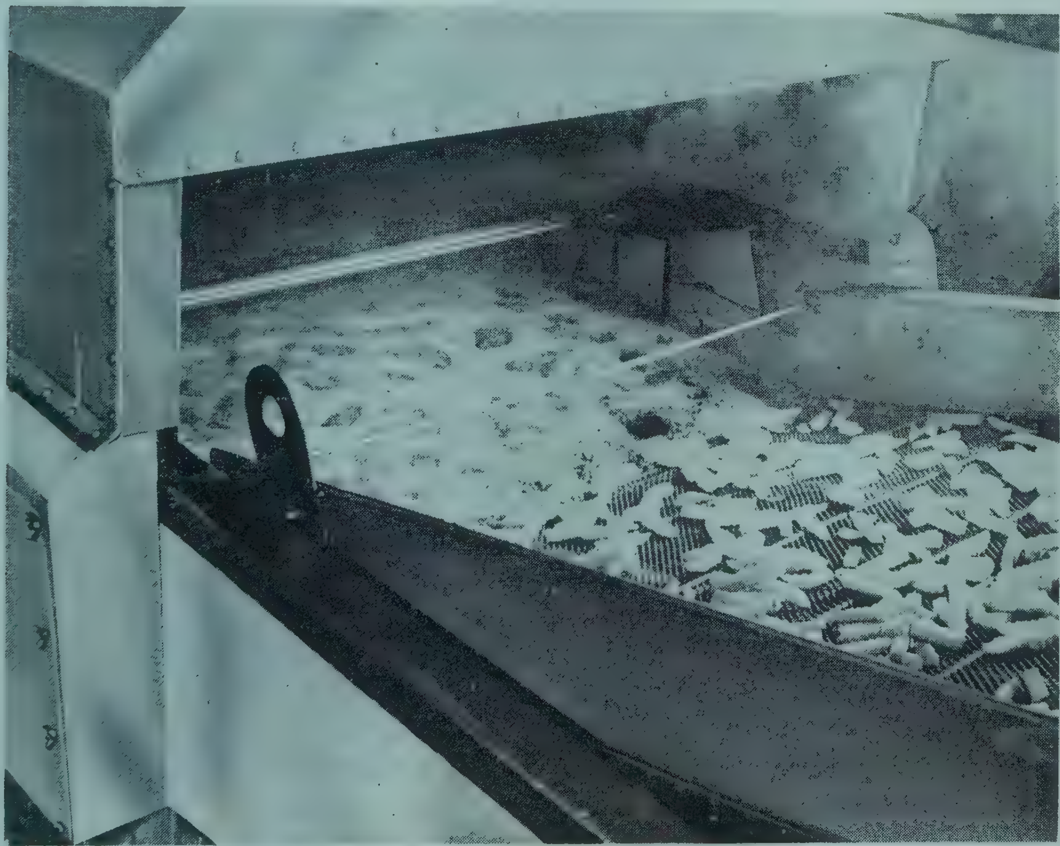
The blanched potato strips are fed into the fryer at a carefully regulated rate. Various types of conveyors are used to carry the strips through the hot fat. One method (Ziemba 1950) is to place the strips in small perforated trays or baskets mounted on an endless chain. The trays are submerged in the fat and conveyed from one end of the fryer to the other. A draper-type conveyor is used by some processors. Others use specially designed equipment.

In the frying process the French-fry strips become golden brown in color. Close attention to and control of frying conditions are essential in order to obtain a product which has the desired surface color and the proper internal textural characteristics when removed from the fryer. A raw flavor and texture will be noted, for example, in undercooked potatoes, while overcooked potatoes will tend to have concave surfaces and collapsed centers. The center of the strip may separate from the outer portion in the form of a core before the surface attains the desired color, if frying is too slow. On the other hand, the center may be partially raw and the surface color excessively dark if frying is too fast and at too high a temperature. Only a small margin of time exists between either overcooking or undercooking and the proper cook. This margin may be as short as a half minute and as long as one minute. Constant supervision is required to make necessary adjustments for the frying characteristics of different lots of potatoes and for varying loads on the fryer. The end result is a function of heat, moisture, and the color-producing reaction of reducing sugars with nitrogen-containing compounds. Fat absorption enhances flavor but excessive amounts give the product an undesirable oily surface. Fat absorption varies to some extent with specific gravity of the raw potatoes, with size of strips, and with retention time in the heated oil.

Variations in extent of frying are made by the processor to meet the requirements of different outlets for his product, particularly for the institutional trade and for the home consumer. Restaurants, for example, desire French fries that can be prepared as needed by finish frying in deep fat to develop color and crispness. To meet this need the processor produces what is known as a "par-fried" or "oil-blanched" potato. Par-fries require but a minimum of frying at the processing plant. Products destined for the home consumer are fried more completely since the home user frequently does not have a deep fat fryer and must depend upon a

hot oven or a broiler to prepare the frozen French fries for serving. This accomplishes some browning and crisping as well as heating.

Frying can be completed in one fryer or in two fryers in series. These methods are known as the single-stage and the two-stage systems. Both are used successfully and proponents of each claim certain advantages. In the two-stage system the blanched strips pass through the first fryer during approximately half the cooking time and are then conveyed to the second fryer, which is similar in design to the first, for completion of



Courtesy of J. R. Simplot Co.

FIG. 63. FRENCH FRIES (CRINKLE CUT) EMERGING FROM THE FRYER

frying. This system increases the rate of throughput and is thought by some processors to permit more even color development and to give greater flexibility of operation. The blanched pieces entering the fat in the first fryer impose a heavy load on this fryer for initial heating of the strips and for water evaporation. Consequently, the temperature of the first fryer tends to be lower than that of the second. Frying is finished in the second fryer where a somewhat higher and more nearly optimum temperature for completion of cooking and color development can be maintained. In the transfer from the first to the second fryer the strips

are turned over which insures even color development and avoids light areas caused by two or more pieces sticking together throughout the frying process. However, single-stage fryers can be so designed and operated as to give the necessary control of frying. Uniformity of color can be achieved by turning or agitating the strips while they are conveyed through the fryer.

Fat is supplied to the processor either in drums or in tank car lots. The fat is melted and held temporarily in a tank from which it is pumped to the fryers as needed. Heat should be evenly transmitted to the fat over as great a surface area as possible to avoid local overheating or hot spots. Heating is accomplished by heat exchangers using high-pressure steam or hot liquid of high boiling point. Some processors use direct heat from gas fired burners. Temperatures commonly employed are within the range of 350° to 375°F. The temperature should not be allowed to exceed 390°F., because fat breakdown is greatly accelerated by high temperature.

FACTORS AFFECTING QUALITY OF FAT USED IN FRYING

The fat should be of the highest quality available since it becomes a component of the finished food and may be subject to prolonged frozen storage. Hydrogenated cottonseed oil is generally used for frying. Minor proportions of soy-bean oil are sometimes mixed with cottonseed oil. Other vegetable oils are usually considered too expensive. Efforts are being made by the meat packing industry to develop a satisfactory and economical frying medium from animal fats.

The vegetable oil is hydrogenated, a process of adding hydrogen to the unsaturated fatty acid component of the fat, to increase its stability against rancidification. Hydrogenated shortenings usually have a high smoke point, that is, temperature at which the fat begins to smoke, and are also resistant to foaming and gum formation during frying.

In a continuous frying operation such as is commonly employed by manufacturers of frozen French fries, fresh fat is constantly being added to the fryer to replace that absorbed by the potatoes. The number of hours required for the volume of fresh fat to become equal to the total content of the fryer is known as the "fat turn-over" period. It is desirable to have a fryer which contains a minimum of fat in relation to its frying capacity (ratio of fat to product contained within the fryer) in order to have as short a fat turn-over period as possible. A rate of fat turn-over of around 10 to 16 hours is considered satisfactory by some processors. Under the conditions and practices which generally prevail in the industry, the replacement of fat is sufficiently rapid to maintain the fat within the fryer in good condition and it is usually permissible to continue frying in-

definitely without discarding any fat. Watchfulness is required, however, especially when the fryer is operating below capacity which prolongs the turn-over period, or during shutdowns or other operating difficulties.

Metals such as iron or copper should not come in contact with the fat, since free fatty acids in the fat will dissolve some of the metal. The resulting compounds will, in turn, act as catalysts and accelerate further fat breakdown. Stainless steel is considered the most desirable material for the frying equipment.

Constituents of fat which are volatilized during frying should be carried off through an exhaust system designed to prevent "drip back" into the fat. These constituents, if allowed to re-enter the frying fat, not only cause off-odors and off-flavors but also accelerate fat deterioration.

Particles of potato left behind in the fryer must be removed periodically; otherwise they become charred and affect the quality of the fat adversely. Periodic or continuous removal is accomplished with centrifugals or filters. Frying equipment also becomes coated with gums or other material during frying and must be cleaned as frequently as necessary to prevent accumulation.

Fat may break down or deteriorate in several ways during frying, including (1) hydrolysis, (2) oxidation, and (3) polymerization (see also p. 252). Hydrolysis is caused by a reaction with water or steam which breaks the fat into its component fatty acids and glycerol. As already mentioned, free surface water should be removed from the French-fry cuts entering the fryer to reduce the extent of hydrolysis. The fatty acids have a sharp odor, an acid flavor and a deleterious effect upon quality in fried foods when allowed to accumulate in the fat. Normally, commercial shortenings contain less than 0.1 per cent of free fatty acid but the concentration becomes unavoidably higher during frying. Free fatty acids tend to volatilize to some extent during frying but their volatility is not sufficient to counteract the gradual build-up. Some processors consider a free fatty acid content of one per cent to be the upper limit for satisfactory control of product quality and believe that the fat should be discarded at this point. Analyses for free fatty acid content are commonly used for quality control purposes. A free fatty acid content which reaches a steady state in the range of 0.4 to 0.7 per cent is regarded as normal in continuous frying of French fries.

Combination of atmospheric oxygen with the fat brings about oxidation and causes darkening, foaming, and development of off-odors and off-flavors while frying. An oxidized fat reduces the storage stability of the fried product. The end result of oxidation is readily recognized as rancidity although fats do not normally reach this stage in the frying operation. Although contact with air at the surface of the hot oil is unavoid-

Courtesy of J. R. Simplot Co.

FIG. 64. FRENCH FRIES (REGULAR CUT AND CRINKLE CUT) BEING CARRIED BY CONTINUOUS BELT TO FREEZER

able, excessive oxidation may be avoided by proper handling practices such as, by preventing aeration in the filtering and circulating system used in connection with the fryer.

Polymerization, the third type of deterioration, is essentially a combination of molecules of unsaturated fat to form products of higher molecular weight. Formation of gum or gummy deposits is usually attributed to polymerization. Oxidation may or may not be involved.

DEFATTING AND COOLING

Excess fat adhering to the French fries is removed immediately after the product emerges from the fryer. One method of defatting is to pass the product over a vibrating screen and to allow the free fat to drain off. Jones (1953) described defatting equipment which consists of a specially designed chamber in which the French fries are shaken and subjected to a high velocity stream of hot air to aid the removal of excess fat. The product is then air-cooled while being conveyed on a wire mesh belt from the frying area to the freezing tunnel. Cooling not only reduces the load

on the freezer but also reduces breakage of the strips when packed before freezing. A final inspection may be given the product at this point to remove dark, over-fried or otherwise defective pieces and to insure uniformity in quality.

Courtesy of J. R. Simplot Co.

Fig. 65. Frozen French Fries Leaving Continuous Belt in Freezing Tunnel

FREEZING AND PACKAGING

Some processors freeze the loose pieces on a continuous belt freezer in a freezing tunnel. Freezing is accomplished at a very rapid rate by this method and requires only twelve minutes at —40°F. (Schaal 1955). Frozen French fries are packed in 9-oz. or 1-lb. cartons using a filling machine to fill to an approximate weight. Each carton is usually weighed and final adjustment in contents made by hand. Five-pound packages or bags are commonly used for the institutional trade. In this case, no attempt is made to obtain an exact weight on each bag but rather to check the overall weight of 6 bags (30-lbs.) which make up the final shipping carton. The retail packages are over-wrapped, cased (usually 24 to a case) and sealed. The cased products are placed in storage at 0°F. or below.

Similar filling procedures are used by processors who package before freezing. The over-wrapped retail-size cartons are frozen in a blast or multiple-plate contact freezer. Plate freezing may take up to two and one-half hours for the product to reach 0°F.

Packaging is a relatively costly operation because of the high labor requirement in packing, weighing, and making the necessary adjustments in weight before automatic closing, wrapping and labelling equipment takes over. However, automatic carton filling and check-weighing equip-

Courtesy of American Box Corp.

FIG. 66. FILLING RETAIL SIZE PACKAGES WITH "TATER-TOTS," A NEW DEEP FAT FRIED SHREDDED POTATO PRODUCT

ment for packaging frozen French-fried potatoes is reported to be in use in at least one plant (Anon. 1957A). Difficulties in handling the product have previously prevented accurate automatic weighing and filling at high speed. In the new equipment a vibrating conveyor separates large and small pieces and feeds them, respectively, to bulk- and dribble-fill stations. Adjustments can be made to fill packages weighing from 9-oz. to 1-lb. at the rate of 30 a minute in a two-stage filling operation. In the first stage the cartons receive the large pieces from the bulk-filler. The filling

Courtesy of American Box Corp.

Fig. 67. Six Packages of Frozen Institutional Par-Fries are Placed in Each Carton

is completed by the dribble-filler which adds just enough of the small pieces to satisfy the automatic check weigher.

INFLUENCE OF STORAGE ON QUALITY OF FROZEN FRENCH FRIES

Dawson *et al.* (1952) reported that home-frozen French fries stored at 0° F. maintained good quality for two months but thereafter became less acceptable with respect to flavor and texture. Kirkpatrick *et al.* (1956) made a more detailed study of the effect of storage on the quality of par-fries stored for 2, 4, 6, and 9 months at 0° F. The French fries were made at harvest and after 2 and 4 months storage of potatoes at 50° F. Maine Kennebec potatoes with an average specific gravity of 1.080 to 1.085 were used. The data indicated that "the best French-fried potatoes were obtained when the samples, par-fried shortly after harvest of the tubers, were fried off immediately or frozen, stored at 0° F., and given the second-stage fry anytime up to nine months after harvest (duration of the test). A slight decrease in color scores with increased time in frozen storage, appeared to be due more to a dullness of the color than to increased brown-

ing. This decrease in color rating was offset by higher scores for lack-of oiliness, crispness, mealiness, and to some extent flavor, in the samples prepared at harvest. However, all frozen samples whether prepared at harvest or after the tubers had been stored at 50° F. for two or four months made satisfactory French-fried potatoes, with the possible exception of the samples from the tubers stored for four months which scored low in mealiness."

U. S. GRADE STANDARDS FOR FROZEN FRENCH-FRIED POTATOES

United States standards for grades of frozen French-fried potatoes were first issued in 1954 by the Agricultural Marketing Service. Grades established include "U. S. Grade A" or "U. S. Fancy," "U. S. Grade B" or "U. S. Extra Standard" and "Substandard." The grade is ascertained by considering both scored and unscored factors of quality. The relative importance of each factor which is scored is expressed numerically on a scale of 100. Maximum numbers of points which may be given for each factor are:

Factors	Score Points
Color	30
Defects	40
Texture	30
Total Score	100

"U. S. Grade A or U. S. Fancy is the quality of frozen French-fried potatoes that possess similar varietal characteristics; that possess a good flavor; that possess a good color; that are practically free from defects; that possess a good texture; and that score not less than 85 points when scored in accordance with the scoring system outline. . ."

"U. S. Grade B. or U. S. Extra Standard is the quality of frozen French-fried potatoes that possess similar varietal characteristics; that possess a reasonably good flavor; that possess a reasonably good color; that are reasonably free from defects; that possesses a reasonably good texture; and that score not less than 70 points when scored in accordance with the scoring system outlined. . ."

"Substandard is the grade of frozen French-fried potatoes that fail to meet the requirements of U. S. Grade B or U. S. Extra Standard."

"Good color" ("A" Grade) means that the frozen French fries "possess a characteristic light cream to golden color typical of properly prepared frozen French-fried potatoes; that the product is bright, practically uniform in color and after heating is practically free from units which vary markedly from the predominating color." "Reasonably good color" ("B"

Grade) means that the product "may possess a variable color ranging from light cream to brown typical of frozen French-fried potatoes; that the product may be dull but not off color and after heating, the variation in color of the units does not seriously affect the appearance of the product." Color models have been prepared by the Agricultural Marketing Service for use in connection with color grading work.

Product meeting the "A" classification must be "practically free from defects." Defects refer to the "degree of freedom from harmless vegetable material, dark carbon specks, unpeeled areas, broken pieces, small pieces, slivers and irregular pieces, and from units blemished (including those seriously blemished) by sunburn, hollowheart, burned ends, abnormal discoloration, dried cut surfaces, or by other means." The product must be "reasonably free from defects" to meet the "B" grade.

"A" grade product must have "good texture." This means that "the external surfaces of the units are moderately crisp, show no noticeable separation from the inner portion, and are not excessively oily; the interior portions are well cooked, tender, and practically free from sogginess." A "reasonably good texture" is permitted for the "B" grade. This means that "the external surfaces of the units may be slightly hard or slightly tough, show no more than a moderate separation from the interior portion, and are not excessively oily; the interior portions are well cooked, reasonably tender, and reasonably free from sogginess."

Factors which are considered but not given a numerical score include varietal characteristics and flavor. "Good flavor" means "the good characteristic flavor and odor of properly prepared French-fried potatoes. Such flavor is free from rancidity and bitterness; from pronounced scorched, or caramelized flavors and from off-flavors and off-odors of any kind. "Reasonably good flavor" means that the product may be somewhat lacking in good flavor and odor but is free from objectionable flavors and objectionable odors of any kind."

QUALITY CONTROL

Quality control of frozen par-fries and French fries usually begins with determinations of specific gravity, analyses for sugar content, and/or laboratory-scale frying tests of representative samples of the potatoes to be used for processing. This information enables the processor to select raw material and to specify the conditioning treatment, if any, that must precede processing. Similar tests are made after conditioning as a check on effectiveness of this treatment and to facilitate the correct choice of blanching and frying conditions in the plant. The processor is able to control the quality of his product through records of the quality of his

raw material and of the partially processed product at different stages of processing. Samples of the final product are frequently taken to the laboratory and reheated for serving according to consumer use instructions. An examination is made for color and trimming defects or defective pieces, and textural characteristics are appraised by hand manipulation or by tasting.

Flavor, surface color, fat absorption, form and symmetry, external texture (crispness) and internal texture (mealiness) were considered by Benes *et al.* (1941) as the most important quality factors for French-fried potatoes prepared for restaurant serving. It was pointed out that the color should be a light golden brown without mottling of darker brown or black spots or streaks. The strips should be regular in form and fairly uniform in length. Crispness without hardness, leatheriness or gumminess is desired and the interior should be mealy like a good quality baked potato without separation between core and crust. Attention should also be given to the detection of bitterness, off-flavor or rancidity.

Buyers frequently set their own standards of quality for the finished product. Such standards may concern piece size, color, fat content, and number of pieces per package, as well as package label, weight, and instructions for use. Some of the buyer's specifications may vary somewhat, depending upon consumer preference in the particular area in which the product is to be consumed. Fat content in the final product is sometimes used as a quality standard. The fat content may vary appreciably among different processors according to raw material, frying practices, and other processing conditions. A buyer may therefore specify a maximum fat content or a satisfactory range of variation. The fat content of frozen French fries packed for retail trade is usually about 5 to 7 per cent and that of the par-fried product around four per cent. These figures are considerably lower than those usually found for French-fried potatoes prepared in the home.

To a large degree, however, the quality of frozen French-fried and other potato products is very difficult to specify in analytical terms. Much must be left to personal judgment and opinion, particularly with respect to such qualities as texture and flavor. The quality control man employed by the processor must, therefore, use a combination of objective and subjective tests which will insure consumer satisfaction.

FROZEN POTATO CO-PRODUCTS

A flow sheet showing the principal processing steps involved in the preparation of French fries and a number of frozen co-products is given in Fig. 68.

Potato Patties

This is a versatile product that can be French-fried, skillet fried, boiled for mashing, baked, broiled, or prepared au gratin. Each patty is uniform in size and shape which contributes to ease of serving and portion control. It was developed by the Ore-Ida Potato Products Co., Inc. (Anon. 1957E) and introduced to the market about 1953.

In the manufacture of potato patties, slivers and short pieces or nubbins separated from the French-fry processing line are steam blanched and cooled and shredded or chopped. Potatoes which are too small for

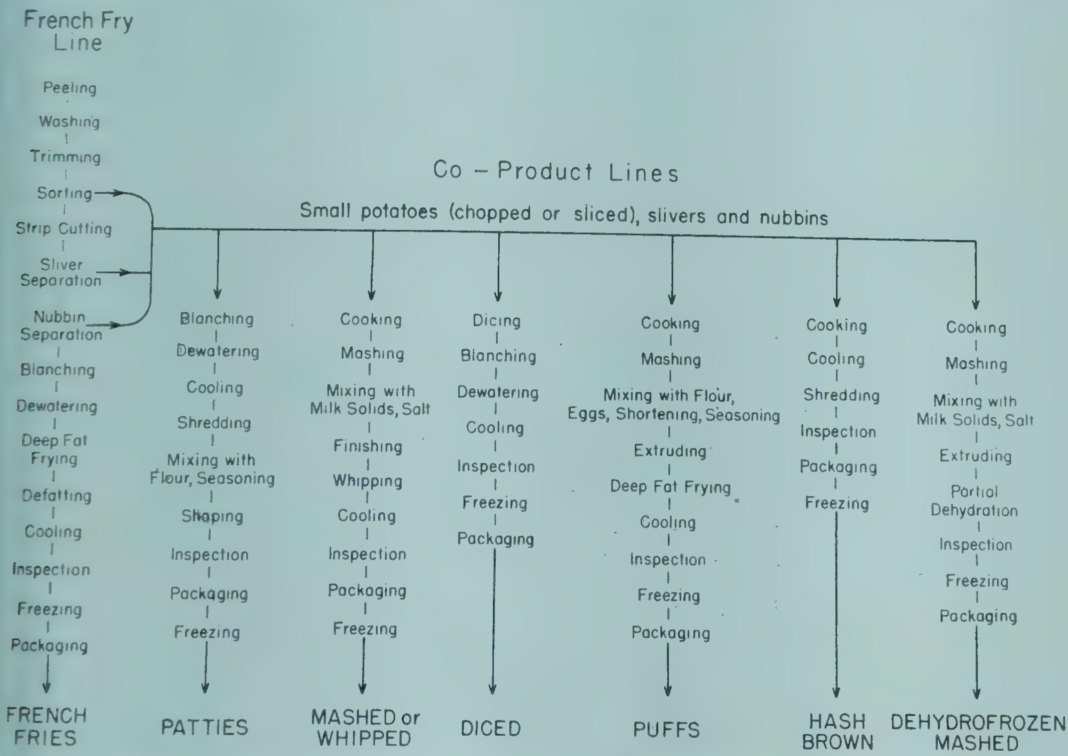


Fig. 68. Flow Sheet for Processing Frozen French Fries and Other Frozen Potato Products

making French fries are also used for patties. These are sliced or shredded and processed in the same manner as slivers and nubbins. Small whole potatoes may also be partially cooked in a steam or hot water blancher before slicing or shredding. Shredding after cooking is thought to give a product better flavor and frying characteristics than does shredding before partial cooking or blanching. The final shredded or chopped material is mixed with potato flour or rice flour and salt, monosodium glutamate or other seasoning. Onion powder is added in some cases for added flavor. The mixture is fed to a patty-forming machine which forms either round or rectangular patties weighing three ounces each. The prod-

uct may be frozen before or after packaging. Patties are placed on waxed paper to keep them separated in the carton.

Diced Potatoes

This product is intended primarily for frying as hash-brown potato but may be used in potato salad or for general purposes. Small potatoes, slivers and nubbins are run through a dicer to produce pieces $^3/_8$ in. x $^3/_8$ in. x $^3/_{16}$ in. The dice are dropped onto a blanching belt where they are automatically spread to the desired thickness. Steam blanching is accomplished in approximately three minutes at 212°F. The product is then passed over a dewatering screen, cooled and given a final inspection. Onion flavoring is added when desired. The product may be loose frozen on a belt before packaging or it may be packaged and then frozen in a contact or blast freezer.

Mashed or Whipped Potatoes

By-product material from French fry process-operations is diced and blanched and then watered and cooked with steam. The cooked material is mashed on rolls and dropped into a large continuous mixing tank where skim milk solids and salt are added. The mashed mixture may be passed through a finisher to remove lumps and fiber and also to provide some aeration. The product is vigorously beaten for whipped potatoes. Film lined packages are filled with product by hand or by means of a volumetric piston filler, then placed on portable racks and frozen in an airblast tunnel.

Mashed potato may also be passed through a pulper or extruded through a ricer before freezing to produce a shredded type of product. This is loose frozen, then run through fingered breakers and packaged.

Products destined for use as mashed potatoes are also produced by freezing blanched and cooked slices, cuts or shredded potato. These are prepared for serving by heating in a steam-jacketed kettle or double-boiler. Milk or water is added and the mixture whipped.

A frozen mashed potato product known as "potato whirls" is produced in England (Anon. 1958C). Whole potatoes are peeled by abrasion, trimmed to remove eyes and other defects, then sliced mechanically and cooked in steam-jacketed boilers. Eggs, milk, margarine, seasoning and other ingredients are added during mashing. The final product has a very creamy texture. Individual portions are given a whirl or spiral configuration by means of a chocolate forming machine specially adapted to this purpose. Four completed "whirls" are packed in polyethylene within a $7^1/_2$-oz. carton and frozen.

Hash-Brown Potatoes

Small whole potatoes are completely cooked, cooled, and shredded with special equipment. The product is packed loose in cartons before freezing. By-product material from French-fry production lines also serves for producing hash-brown products. This material is shredded or diced followed by blanching and cooking.

Potato Puffs

Another use for slivers and small pieces of potato is for the preparation of frozen potato puffs. The raw material is cooked with steam, mashed and mixed with wheat flour, eggs, vegetable shortening and seasoning. The following basic formula has been suggested (Anon. 1955); cooked peeled potatoes, 79.5 per cent; butter or margarine, 4.5 per cent; cream (light), 9.0 per cent; egg yolks, 3.5 per cent; and egg whites, 3.5 per cent. The mixture is usually extruded in the form of croquettes, allowed to cool and fried in deep fat. Dimensions of the puffs are approximately $^3/_4$ in. in diameter by $1^1/_2$ in. long.

Au Gratin Potatoes

A sauce consisting of milk, cheddar cheese, salt, monosodium glutamate, and pepper are combined with cooked diced potatoes in the approximate ratio of 2/3 potato to 1/3 sauce. Rice flour, shortening, and sugar may also be added. A topping consisting of cheddar cheese, toasted bread crumbs, and margarine is sprinkled on the product in preparation for freezing.

Rissole Potatoes

Small whole potatoes are blanched and fried in deep fat to a golden brown color.

Potato Cakes

According to Tressler and Evers (1957) "Potato cakes are prepared by incorporating beaten eggs and salt with cold mashed potatoes or grated raw potatoes. The chopped parsley, chopped celery or celery seed, grated onion, small and irregular blanched strips of potatoes rejected from the French-fry line may be used after they have been cooked further on a wire-mesh conveyor in a continuous steam-blancher and then inspected and riced in a pulper. If grated raw potatoes are used, more eggs will be required to hold the cakes together than if either cold mashed potatoes or the steam-blanched, irregular strips from the French-fry line are used. After thorough mixing of the ingredients, the potato mix is formed into

cakes which are dipped either in fine bread or cracker crumbs, or flour, and then fried by the shallow fry method. Midway through the frying the cakes are flipped over and browned on the other side. After cooling, the potato cakes are packed either in consumer-size cartons which are closed and overwrapped before freezing, or are placed on a tray as a component of a frozen precooked dinner."

Shredded Potato

A new deep fat fried, shredded potato product, was recently introduced (Anon. 1958B). This product is in the form of small "bite-size" logs approximately $1^1/_8$ to $1^1/_4$ in. in length by $^3/_4$ in. in diameter. It is produced from small potatoes, slivers and broken pieces which are shredded, blanched and mixed with flour, salt, monosodium glutamate and spice. The mixture is extruded and fried in deep fat, then frozen and packaged.

Dehydrofrozen Products

Dehydrofreezing is a relatively new method of food preservation developed by the Western Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture (Talburt and Ramage 1957). As the name suggests, dehydrofreezing consists of freezing fruits and vegetables from which slightly more than half the water has been removed, enough to reduce weight and volume by half. No loss in quality is suffered by the commodity when dehydrated to this extent and the frozen product has the advantage of substantial savings in container, shipping, storage and handling costs (Rasmussen *et al.* 1957). A new type of continuous dehydrator, called a belt-trough dryer was developed for use in the dehydrofreezing process.

Dehydrofreezing has been applied experimentally to several potato products. Dehydrofrozen or "concentrated" mashed potato was recently introduced to the American institutional market. Mashed potato is prepared in the usual manner by cooking, mashing and mixing with milk solids and salt. The mashed product is then extruded and dehydrated in a continuous drier to about 12 to 15 per cent moisture. This is followed by freezing and packaging. Preparation for serving is readily accomplished by addition of hot water or hot milk and mixing to the desired consistency.

Precooked Frozen Dinners

This subject has been discussed in detail by Tressler and Evers (1957). The Maxson Food Systems, Inc., are reported to have produced the first frozen complete meals in 1945. These were designed primarily for the feeding of airplane passengers. French-fried potatoes, potato puffs and

patties were included in certain of the initial list of 18 separate menus. In more recent years frozen dinners have become very popular with the general public and are reported to be increasing more rapidly in volume than are other frozen food products. The variety of frozen potato dishes available in the dinners has also increased tremendously in recent years and now includes French-fried, mashed, whipped, hash-brown, au gratin, baked, roasted, boiled, scalloped, stuffed baked, cottage fried, rissole potatoes, potato cakes and other specialties. A number of these products are prepared for military use in precooked frozen dinners in accordance with military specifications (Anon. 1956D).

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Carl E. Hendel

Dehydrated Mashed Potatoes Potato Granules

INTRODUCTION

Potato granules are dehydrated mashed potatoes in powder form that are quickly converted to mashed potatoes by mixing with hot or boiling liquid. They are a convenience food that may be expected to help the potato industry maintain and perhaps even improve its position in the face of the increasing competition from the many other convenience foods now on the market. They are adapted for use both in the home and in restaurants and other group feeding establishments. They can be reconstituted to a texture that is either dry and mealy, or moist and creamy, according to individual preference.

First introduced into the United States about 1948 as a product for home use, and with military interest greatly stimulated in 1950 and succeeding years by the hostilities in Korea, potato granules have found increasingly wide acceptance, and productive capacity has increased in most years since 1951. The sizable expansion during the past year should bring capacity for the 1958–59 processing season to about 75,000,000 lbs. At this capacity the industry will be using nearly 6,000,000 hundredweights of potatoes, or about 3 per cent of the potatoes used for food. Continued expansion is anticipated. Factors accounting for the rapid growth of this product include not only convenience, but also high quality and moderate cost. Cost is moderate because of the nature of the process used for manufacture, and the high bulk density which results in minimum costs of packaging and of shipping.

The many investigations aimed at improving processes for manufacture of potato granules have been ably reviewed by Olson and Harrington (1951, 1955A and 1955B) and by Kueneman (1957). Hence no summary of the earlier literature will be given here. Attention will instead be devoted to the present status of the industry and to problems that need to be solved to enable the industry to develop most rapidly.

THE "ADD-BACK" PROCESS

Although a number of processes have been developed for the direct production of potato granules, none of them is in commercial use in the

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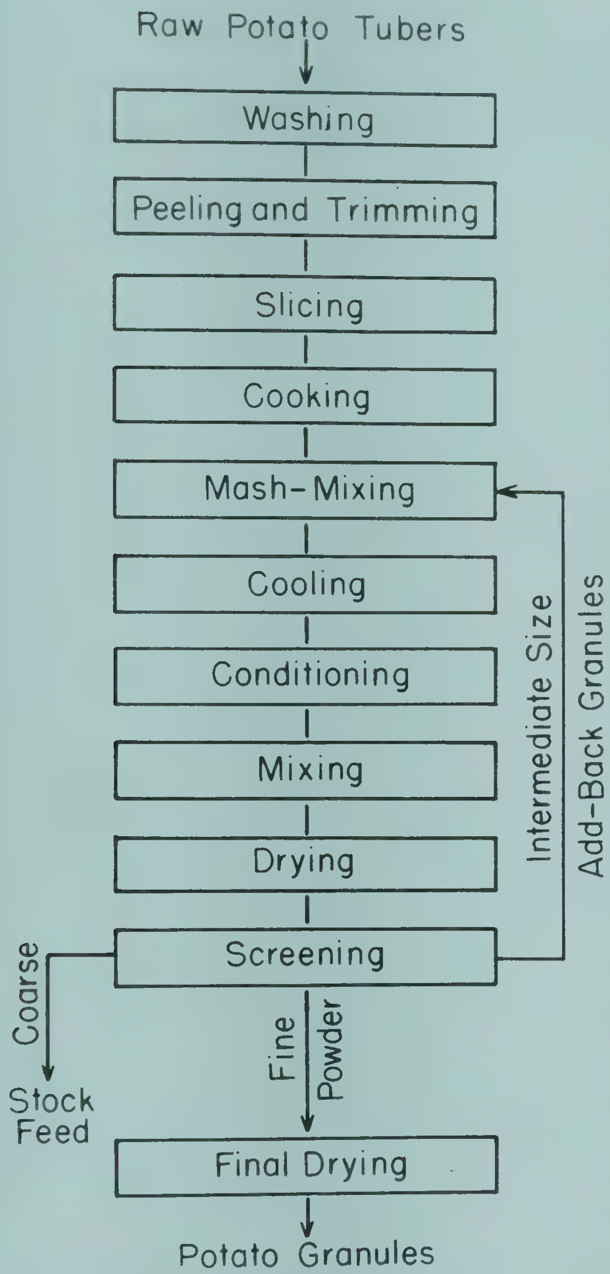


Fig. 69. Schematic Outline of the Add-Back Process for Manufacture of Potato Granules

United States at the present time. The one used is the "add-back" process, in which cooked potatoes are partially dried by "adding back" enough previously dried granules to give a "moist mix" which after holding can be satisfactorily granulated to a fine powder. The procedure is outlined schematically in Fig. 69. Following peeling and trimming, the potatoes are usually sliced (thickness $^5/_8$- to $^3/_4$-in.) to promote uniformity of

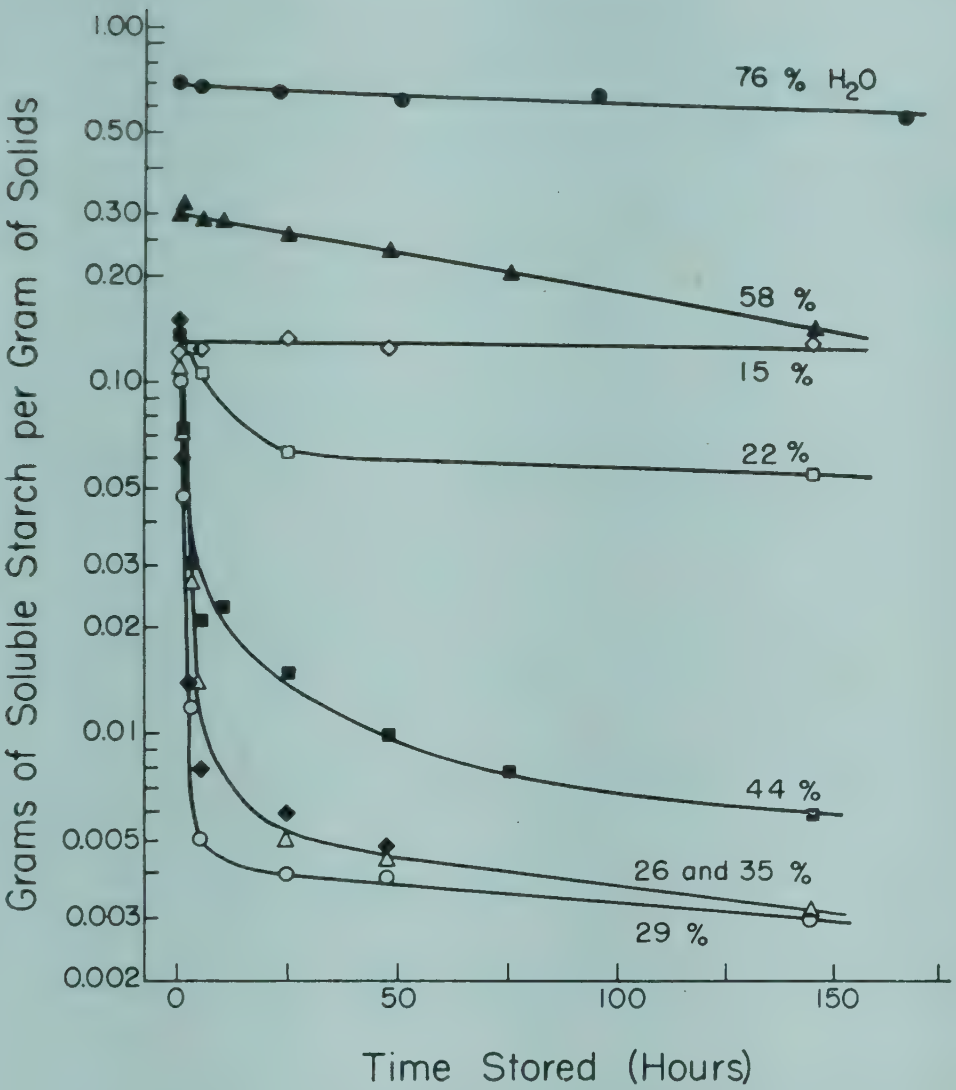
cooking. Cooking is in steam at atmospheric pressure, with the potatoes on a moving belt at a depth of about 6 to 8 in. Cooking time depends on the raw material and on the altitude, but is usually in the range of 30 to 40 minutes. Mashing and mixing with the dry add-back granules is then performed, and the resultant moist-mix is cooled to approximately 60 to 80°F. It is then conditioned by holding for about one hour at this temperature, mixed, dried in one or two stages to about 12 to 13 per cent moisture content, and screened. Material coarser than about 60 to 80 mesh is returned to the process as add-back for succeeding cycles. A part of the fine material passing through the screen is also returned as add-back, but the part to be used as product of the cycle is further dried to a moisture content of about six per cent. A small portion of very coarse material, retained on a screen of about 16-mesh size, is removed from the process because it does not absorb moisture from the cooked potatoes fast enough to be helpful. About 12 to 15 per cent of the material is removed as packout; the remainder is used as add-back.

The early workers who contributed to development of the process included Bunimovitch and Faitelowitz (1936), Volpertas (1939 and 1944), Rendle (1943 and 1945), Bar (1943), and Rivoche (1948 and 1950). Much improvement since 1950 has resulted from efforts of the commercial manufacturers and from those of several research institutions including the Quartermaster Food and Container Institute for the Armed Forces. Developments of one commercial concern have been reported by Kueneman and Havighorst (1955). An extensive potato granule research program has been in progress at the Western Regional Research Laboratory during this period.

GRANULATION AND AVOIDANCE OF CELL RUPTURE

Essentials in manufacturing potato granules are (1) minimizing rupture of the potato cells, and (2) satisfactory granulation. Rupture of cells releases free starch; the product becomes unduly sticky or pasty if this is excessive.

Satisfactory granulation is necessary to avoid graininess or lumpiness in the product from this process. The packout granules should for the most part be unicellular, and furthermore it is necessary that the add-back material contain a certain proportion of these fine granules. Poor granulation is self-perpetuating. If it begins, the proportion of large-size granules in the add-back will tend to increase progressively with continued recycling. The larger particles do not absorb moisture rapidly enough to lower the moisture content of the freshly cooked potatoes to such a point that granulation occurs readily. The proportion of large-size granules may become so high that alteration in the process—for example increasing

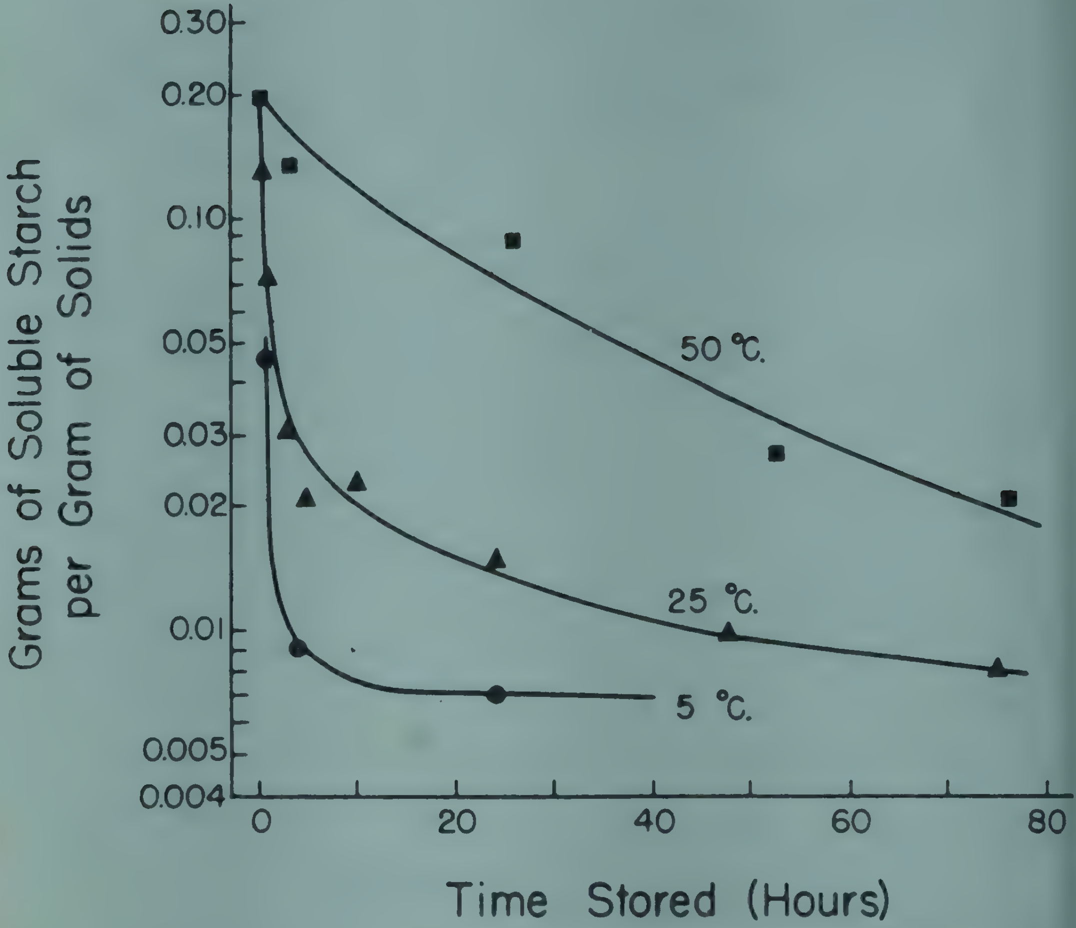


From Potter (1954)

FIG. 70. EFFECT OF MOISTURE CONTENT OF MOIST-MIX ON RETROGRADATION OF STARCH

the proportion of add-back to cooked potatoes—will be necessary to permit maintenance of pack-out particle size within established specifications and to avoid excessive quantities of the very coarse material that must be removed from the process.

Granulation is markedly improved by the holding, or "conditioning" or "tempering" of the moist mix. Olson *et al.* (1953) have shown that granulation is improved by decreasing moisture content of the moist mix in the range of 45 down to 35 per cent moisture. Granulation was also improved by lowering the temperature of conditioning. Olson and Harrington (1955A) reported a 20 per cent yield of smaller than 70-mesh



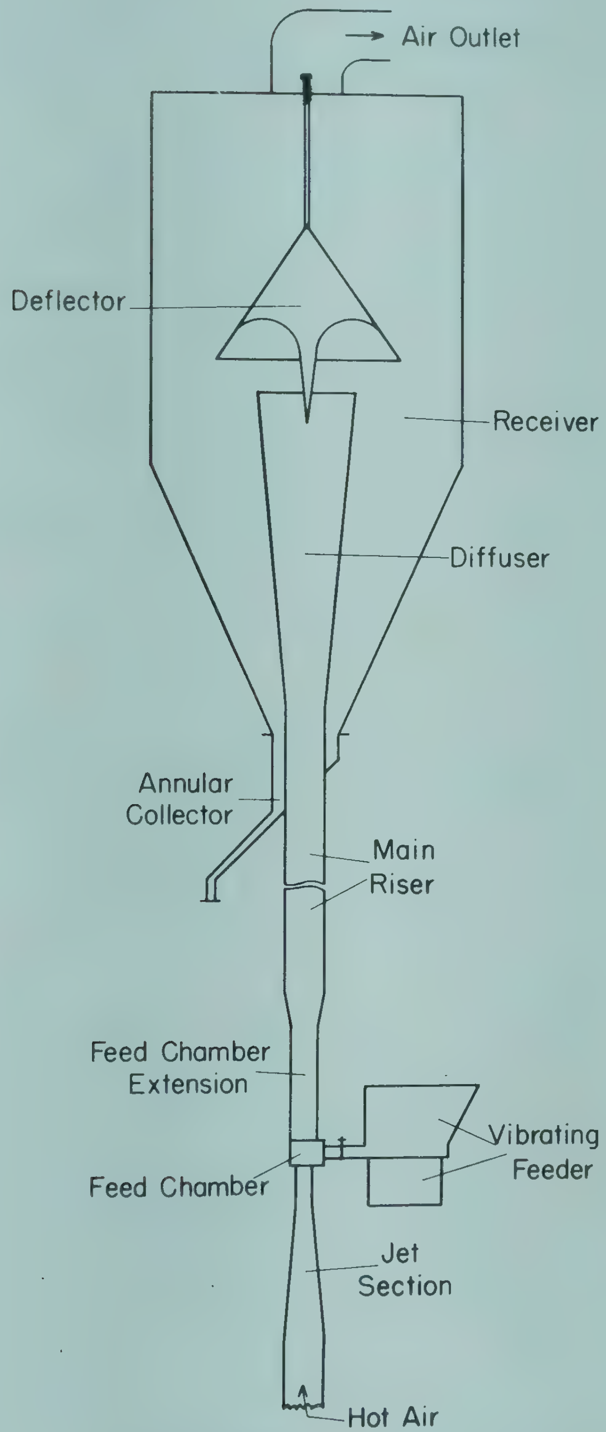
From Potter (1954)

Fig. 71. Effect of Storage Temperature on Retrogradation of Starch in a Moist-Mix

product when the moist mix was tempered at 136°F. compared to 62 per cent smaller than 70 mesh for moist mix tempered at 39°F.

Potter (1954) showed that both in moist mixes and in potato starch gels there is a decrease in soluble starch during conditioning. Also the swelling power of the moist mixes decreases during conditioning. The conditions causing fastest change in these properties of the starch were found to parallel those that improve granulation of the potato granules during conditioning. It was therefore concluded that changes in physical properties of starch play an important role during the conditioning or tempering period used in the manufacture of potato granules.

Fig. 70 from the work of Potter (1954) shows that decrease in soluble starch during tempering of a moist mix at 77°F. was most rapid at a moisture content of 29 per cent, nearly as rapid at 26 and 35 per cent, and that no change occurred at moisture contents of 15 and 76 per cent.



From Olson et al. (1953)

FIG. 72. AIR-LIFT DRIER, FOR AIR-SUSPENSION DRYING OF POTATO GRANULES

Fig. 71 shows the acceleration of change in free starch in a moist mix with decrease in temperature from 50° to 5°C.

The decrease in soluble starch, or retrogradation, is considered due to an association of the starch molecules, probably by hydrogen bonding either directly or through molecules of water bridging between active sites on the starch molecules.

MANUFACTURING OPERATIONS

To minimize cell rupture and resultant release of free starch, all manufacturing operations are carried out as gently as possible. Mashing is now usually by the mash-mixing technique in which the hot cooked potatoes are mixed with the dry add-back granules until an apparently homogeneous moist-mix is obtained (Harrington *et al.* 1958). Indications are that the repeated mild shearing and pressing action of the dry and partially dry granules against the cooked potato tissue causes separation of the latter into individual cells with fewer broken cells than when mashing is carried out by other means, for example by extrusion or on mashing rolls.

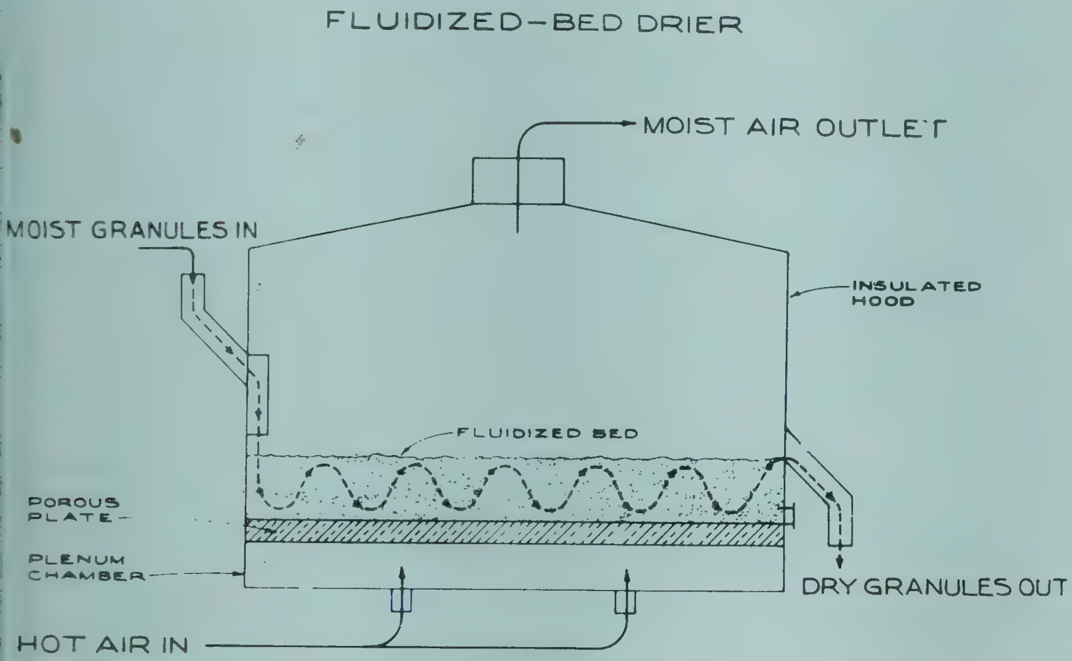
Cooling of the moist-mix is effected gently in a shaker-cooler in which the product is passed over a vibrating screen of very fine mesh, through which cool air is passing.

In present practice, conditioning of the cooled moist-mix is usually on moving rubber belts, approximately four feet in width and depressed at the middle to form a wide "V." Depth of product at the center of these belts is only about 6 to 9 inches. It is thus possible to avoid excessive compression (which results in some agglomeration) and the mechanical damage from auger screws, that occurred in deep beds that have been used for conditioning.

Since some agglomeration does occur during conditioning, a gentle mixing is often employed at the end of the conditioning period. A scalping reel is frequently included at this point to remove any very large agglomerates and any bruised portions of potato tissue that were not removed during the trimming. Regions of the potato that were bruised during harvesting or handling may undergo discoloration during storage of the fresh potatoes. Removal of all of these discolored regions by trimming is both difficult and expensive. It is an advantage of the add-back process that these discolored regions are relatively hard and do not break up during mash-mixing. Hence they can be removed by scalping following the conditioning. This feature of the add-back process makes for both better quality of product and lower cost of production than is possible with other methods of manufacture.

The product then goes to the driers, where again every effort is made

to minimize cell damage. Several kinds of driers are in use. The product is usually air-borne while dried, thus avoiding agglomeration that would occur if the particles were in contact with one another during the drying, for example as in tray drying. The principle of avoiding abrasive damage during drying is illustrated in the air-lift drier in Fig. 72. The drier consists of a vertical tube with upward flow of hot air. The moist feed enters at the bottom. Drying occurs as the product is rising in the tube, and in the inverted cone diffuser at the upper end of the tube. The particles tend to remain suspended in the riser and in the diffuser until



From Neel et al. (1954)

FIG. 73. CONTINUOUS FLUIDIZED-BED DRIER FOR USE IN FINISH-DRYING OF POTATO GRANULES

they have dried to such a point that their weight is low enough for them to be swept over the top of the diffuser into the collector. The air-lift drier operates at relatively low air velocities (1500 to 2000 feet per minute), with minimum damage to the potato cells.

Damage can occur in pneumatic driers, especially with higher air velocities. Cooley *et al.* (1954) at the University of North Dakota demonstrated that damage occurred in both vertical and horizontal duct driers of 8-inch diameter at air velocities of 70 and 73 feet per second (4200 and 4400 feet per minute).

Following drying to about 12 to 13 per cent moisture, the product is screened. The final drying of the packout granules or product of the cycle is carried out in a fluidized bed drier, shown schematically in Fig.

TABLE 38

TEMPERATURE, RESIDENCE TIME, AND MOISTURE CONTENT RELATIONS IN THE CONTINUOUS FLUIDIZED-BED DRIER[1]

Feed Rate, Lb./Hr. per Sq. Ft. of Bed	Residence Time of Granules in Bed, Minutes	Temperatures, °F.				Moisture Content of Product
		Inlet Air	Exhaust Air	Within the Bed	Product	Wet Basis, Per cent[2]
18.0	28	300	114, 136[3]	139, 151[3, 4]	142	5.0
30.0	17	400	118, 143	141, 162	150	5.0
18.0	28	400	136, 162	172, 192	174	3.0

1 From Neel *et al.* (1954).
2 Moisture content of feed, 11.0 per cent.
3 Measured respectively 2 in. downstream from inlet, and 2 in. upstream from outlet.
4 Measured with thermocouples, 3/4-in. above the porous-plate bottom of the fluidized-bed drier.

73. This drier, developed at the Western Regional Research Laboratory, consists of a chamber with a porous ceramic or very fine mesh screen bottom through which heated air flows. The granules, entering continuously at one end of the drier and leaving at the other, are suspended or fluidized by the air from the porous bottom of the bed. The appearance within this interesting piece of equipment is illustrated in Fig. 74. The granules offer no resistance whatever to lateral movement, flowing like a liquid. Drying occurs during the 10 to 30 minute residence time. The inlet air temperature can be quite high without scorching the product because transfer of heat occurs so rapidly that none of the granules is exposed to a very high temperature. The interesting temperature relations are indicated in Table 38.

STORAGE

Potato granules are subject to two principal types of deterioration during storage: Non-enzymatic browning and oxidative deterioration.

Non-enzymatic Browning

This form of deterioration has been widely experienced in dehydrated potatoes in dice form, and measures for control of it in potato granules are the same as those for dice, namely use of potatoes of low browning tendency, sulfiting, drying the product to low moisture content, and avoiding high storage temperature.

Non-enzymatic browning has a very high temperature coefficient, and the rate is exponential with temperature, following approximately the Arrhenius relation (Legault *et al.* 1947 and 1951; Hendel *et al.* 1955A). With *each* increase in temperature of 18°F., the rate increases about 5- to 7-fold, depending on the moisture content and the temperature. Taking 6-fold as an average value, the rate increases about $6 \times 6 = 36$-fold with a temperature increase of 36°F., and about $6 \times 6 \times 6 = 216$-fold

Courtesy of J. R. Simplot Co.

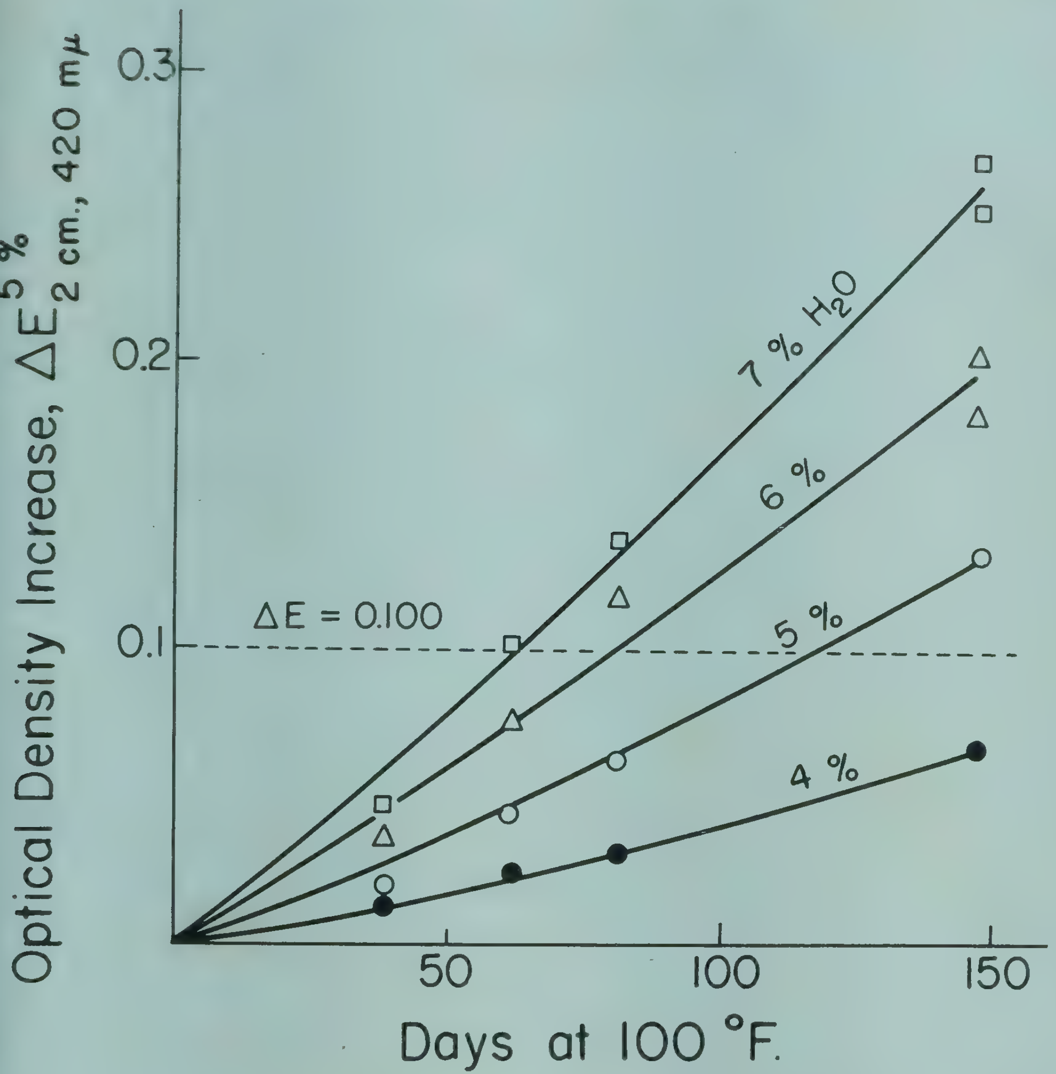
FIG. 74. FLUIDIZATION OF POTATO GRANULES IN FLUIDIZED-BED DRIER

with an increase of 54 F. Lowering the storage temperature is thus potentially by far the most effective method of controlling non-enzymatic browning. Often control of temperature is not feasible, but a combination of the other protective measures can usually provide satisfactory protection against browning.

Use of potatoes with a low content of reducing sugars is one of the best control measures since scorching during drying is also reduced. Non-enzymatic browning is approximately proportional to the content of reducing sugars, although exceptions to this general rule do occur. Potatoes with less than one per cent of reducing sugars on a dry basis are best for manufacture of potato granules, but through much of the year the reducing sugar content of the available potatoes is much higher —2, 3, or even 4 per cent. The problem is that in order to hold the fresh potatoes without undue sprouting, they must be stored at temperatures of about 42 or 40°F. or lower, depending on the length of time the potatoes are to be held. At 34 to 38°F. potatoes in Idaho can often be kept from harvest in September or October until the end of the following June or even longer. But at these low temperatures there is a large increase in the reducing sugar content of the potatoes. Some reduction in sugar content can be obtained by holding the fresh potatoes for 1 to 2 weeks at about 70°F. before processing, but this conditioning treatment is only partially effective. A more promising procedure is to avoid storing the potatoes below about 50°F. as may become feasible by use of sprout inhibitors such as maleic hydrazide (MH-40 or MH-30), methyl ester of naphthalene acetic acid (MENA), or isopropyl N-(3-chlorophenyl) carbamate (CIPC, or Chloro IPC) (see p. 148). Problems remain to be solved in developing methods of using these inhibitors that will be most effective, least expensive, and that will not result in greater spoilage, but there seems little doubt that certain inhibitors will be widely used in the future for maintenance of processing quality in potatoes for the potato granule industry.

Sulfite is effective in retarding browning. Precise quantitative data are not available for potato granules, but the amount needed for a given degree of protection is presumably similar to that in the case of dehydrated potato dice. From data available for dice (Legault *et al.* 1951; Hendel *et al.* 1955B) and on the basis of commercial experience in the manufacture and distribution of potato granules, it appears that with presently available raw material, sulfite at a level of about 200 p.p.m. is necessary in potato granules to be distributed within continental United States if they are to have satisfactory resistance to non-enzymatic browning in the period before they reach the consumer.

Sulfite is also effective in retarding scorching during drying, and in addition helps reduce a graying that sometimes occurs during processing. This graying may be the same as the aftercooking darkening of potatoes. The chemistry of aftercooking darkening has been competently reviewed by Smith (1957); also see p. 85. He reported that sulfite is quite effective in reducing this darkening.



Courtesy of Hendel, Burr and Wood

FIG. 75. EFFECT OF MOISTURE CONTENT ON NON-ENZYMATIC BROWNING OF POTATO GRANULES DURING STORAGE AT 100°F.

The fourth method of reducing browning of potato granules during storage is to lower the moisture content. The effect of moisture content on browning of potato granules during storage at 100°F. is indicated in Fig. 75. Although lowering the moisture content and avoiding high temperature of storage are effective against browning of the finished product during storage, they, of course, play no part in controlling scorching during the drying, as do sulfiting and use of potatoes of low sugar content.

Oxidative Deterioration

Oxidative deterioration differs from non-enzymatic browning in several respects:

1. The rate of oxidative change is not markedly affected by temperature of storage. Burton (1949) estimated that the rate is increased only about 1.2 to 1.4 times with a temperature rise of 18°F.

2. Packing in nitrogen greatly retards oxidative deterioration, but it has little effect on rate of browning.

3. Most strikingly, although lowering the moisture content *slows down* non-enzymatic browning, it *accelerates* the oxidative deterioration (Burton 1949; Hendel *et al.* 1951).

Nitrogen packing is used commercially for control of oxidative deterioration. Most of the oxidation is prevented, but a small amount occurs presumably because of the small percentage of residual oxygen that is usually present. The atmosphere of the package usually contains about 0.5 to 1.5 per cent oxygen. When pin holes occur in foil laminate heat-sealing bags usually used for retail distribution, oxidative deterioration may be severe. Nitrogen packing is of no further benefit after the container has been opened.

Although packaging in an inert atmosphere is quite effective in preventing oxidative deterioration, packaging and material costs are so high that other methods of preventing oxidative changes in potato granules are needed. Considerable attention is now being given to use of antioxidants to control oxidation. A patent granted to Campbell and Coppinger (1955) of the Western Regional Research Laboratory specified three processes of stabilizing dehydrated vegetables: treatment of the product with antioxidant before drying, enclosing the dehydrated product in a sealed container together with a pad containing a volatile fat-stabilizing antioxidant, and mixing the dried product with an edible dry composition containing a volatile antioxidant and placing it in a sealed container. Numerous classes of antioxidants were specified, including butylated hydroxyanisole (BHA) either alone or in combination with propyl gallate and citric acid. BHA and numerous other antioxidants have sufficient volatility to permit distribution throughout the dried material by diffusion in the vapor phase. Antioxidant levels of 0.1 to 0.001 per cent (1,000 down to 10 p.p.m.) were preferred.

In extension of this work at the same laboratory, it was found that some people are able to detect BHA in potato granules at levels of 10 p.p.m. (dry basis) and even lower. The sensation has been described as bitter, medicinal, and astringent. At low levels there is often a delay of 15 to 60 seconds before the BHA is detected. Other antioxidants can similarly be detected at low levels. Oxidation has been inhibited at levels down to 1 p.p.m., but effectiveness was reduced at levels of one-third p.p.m. A desirable range for use of BHA appears to be about 1 to 5 p.p.m. In trials to date, butylated hydroxytoluene (BHT) has

seemed a little more effective than BHA. In case BHA and BHT act on different constituents in the potato granules, a desirable treatment pending further research appears to be 2.5 p.p.m. of each of these two antioxidants. A convenient and effective procedure for addition of the antioxidants to potato granules is to intimately incorporate them with enough granules to give a concentrated mix containing 5,000 p.p.m. of antioxidant, and then to add enough of this concentrated mixture to the main lot of granules to give the desired level of antioxidant.

Stephenson *et al.* (1958) have found BHA quite helpful in retarding oxidation in potato granules, especially when used in conjunction with nitrogen-packing.

From the foregoing it might be assumed that effects of antioxidants are well understood, and that present methods of using them are entirely adequate. This is not the case, and in fact development of improved and less expensive methods of controlling oxidative deterioration is one of the most important needs of the potato granule industry. As used thus far, antioxidants have been more effective against oxidative odor than against oxidative flavor. A possible explanation may be that more than one type of constituent contributes to oxidative deterioration, and that constituents with volatile oxidation products are affected to a greater degree by the antioxidants than are those with nonvolatile products.

A comprehensive fundamental investigation is needed to determine the constituents of the potato that contribute to the oxidative deterioration. There is evidence that the fats present in the potato contribute (Burton 1949; Hendel, *et al.* 1951), but indications are that they cannot account for all of the oxidation. It is suspected, for example, that carotenoids may be among other constituents that are involved. Knowledge of the causal factors is urgently needed as a basis for technological investigations aimed at solution of the problems. The ultimate solution may result from selecting more suitable raw material, developing new antioxidants or new methods of using them that are tailored to the product, and/or developing new processing procedures (possibly granules without add-back) that will yield a product with less suspectibility to oxidative deterioration.

QUALITY EVALUATION AND ANALYTICAL PROCEDURES

As for other products, subjective appraisal is the ultimate basis for evaluating quality of potato granules, and this method is the only one available for evaluation of flavor and odor.

Objective procedures have proven useful for measure of color, both natural color of the potato granules and that produced by non-enzymatic browning. Reflectance photometry has been used by Stephenson *et al.*

(1958) and by Harrington and co-workers (unpublished). Soluble color procedures have been used for measure of non-enzymatic browning, soluble colored constituents being extracted in various solutions, for example the ten per cent sodium chloride solution of Stephenson *et al.* (1958), and the 55 per cent ethanol solution of Hendel *et al.* (1950). Concentration of soluble colored constituents which increases with heat damage, is measured photometrically.

Glass standards for visual color appraisal of potato granules have been developed by Nutting *et al.* (1958). Beads of glass comparable in size to individual potato granules are admixed with appropriate pigments to give three stable color standards, designated respectively as good, borderline, and poor color. These standards are in jars. The granules are placed in similar jars that are placed in an illuminator for comparison with the glass color standards. All of these color procedures are in need of refinement as the results do not always correlate well with the color of the reconstituted granules.

Much attention has been given to developing methods of evaluating texture. Wood *et al.* (1955) described a subjective method of appraisal in which test samples are compared against two reference samples of potato granules differing in degree of rubberiness. The "high" control was less rubbery than the "low" control. Five categories of rubberiness were possible in the ranking system that was specified:

A—Less rubbery than high control.
B—Like high control.
C—Between high and low control.
D—Like low control.
E—More rubbery than low control.

Use of reference samples, as in this method, is helpful in reducing uncertainty due to day-to-day and month-to-month drift in judges' memory, and in reducing the number of comparisons that must be made when large numbers of samples are to be intercompared.

Microscopic count of the number of broken cells has been used by a number of investigators to evaluate texture of potato granules from processes not involving add-back (Proctor and Sluder 1944; Campbell *et al.* 1945; Greene *et al.* 1947, 1948, and 1949; and Hall 1953). Within limits the general textural quality of the reconstituted product could be predicted. With granules from the add-back process, no successful application of microscopic count has been found, according to Olson and Harrington (1955A). They suggest as a probable reason the fact that the free starch that is released will adhere to the intact cells during subsequent recycling; they state that as a result microscopic identification of starch liberation and total cell breakage could not be very precise.

Cooley *et al.* (1954) have reported successful use of viscosity measurement of reconstituted potato granules with a viscometer, although it was necessary to rehydrate the granules with appreciably more water than would be used for food preparation.

The "Blue Value Index" of Mullins *et al.* (1955) is easy to use and has proved helpful in process development, correlating well with texture if there are no large differences in procedure or in raw material. An extract of the granules is treated with iodine solution. The intensity of the resultant starch-iodine blue color, measured colorimetrically, is an index of the free starch that is present. However, the Blue Value is a measure primarily of the quantity of straight-chain amylose, and not of the branched amylopectin, which is present in larger quantity than is the amylose. Perhaps for this reason this Index has not proved a very reliable method of comparing texture of granules produced by different manufacturers.

A more direct approach, also proposed by Mullins *et al.* (1957), is the "drop-test." Potato granules are reconstituted under standardized conditions and a round ball of the material is dropped from a fixed height. The diameter of the cake that is formed on impact with a solid surface is a measure of the consistency of the product, the larger the diameter the more mealy the granules. The diameter has correlated well with subjective appraisal of granules from different sources. A comparison of Blue Values, panel appraisal results, and cake diameters for a series of potato granules is given in Table 39.

TABLE 39

COMPARISON OF SENSORY AND OBJECTIVE RESULTS FOR CONSISTENCY OF POTATO GRANULE SAMPLES[1]

Sample No.	Blue Value Index	Texture Rank[3]	Mean Cake Diameter, Mm.
1	35	1.1	71.4
2	133	2.5	65.5
3[2]	139	2.8	60.8
4	77	3.9	58.3
5	103	4.8	56.0
6	149	5.9	52.7

[1] From Mullins *et al.* (1957).
[2] A laboratory sample. The other samples were from various commercial sources.
[3] Textural rank 1 = least rubbery; 6 = most rubbery. Shortest significant range (Duncan) at P = 0.05 = 0.31.

Measure of sulfite content of the potato granules is necessary for production control and for purchase specifications of the Armed Forces and of commercial buyers. The Thompson and Toy (1945) modifications of the Monier-Williams distillation method is very reliable, but it is time

consuming. It is the method required in U. S. Military Specifications (1950). A rapid but less accurate method is the formaldehyde titration procedure of Potter and Hendel (1951). It is in rather common use, and is usually quite satisfactory, but if there is uncertainty it should be checked against the Thompson and Toy distillation procedure.

Measure of moisture content is another essential. The six hour-vacuum oven method of the Military Specifications (1950) is commonly used both for control and as a reference method, although the Karl Fischer procedure (Johnson 1945) and the 40-hour vacuum oven method (Makower *et al.* 1946) are believed more accurate. The toluene distillation method is often used for production control.

Sugar content is usually measured in quality control laboratories by the dinitrophenol method (Ross *et al.* 1946) if a colorimeter is available, or by the picric acid procedure (Ross *et al.* 1946) if one is not. These methods give high results because of the presence of reducing substances other than sugars, but they are rapid and relatively easy to use. In research laboratories it is sometimes feasible to employ methods that remove the non-sugar reducing substances. At the Western Regional Research Laboratory the ion-exchange clarification procedure is used for removal of such substances (Williams *et al.* 1953; Association of Official Agricultural Chemists, 1955A), followed by measure of the sugars by the Somogyi copper method (Assoc. Off. Agr. Chem. 1955B).

SUMMARY

Continued growth of the potato granule industry is anticipated. Product quality is good, and cost is low, the latter resulting in large part from the moderate costs of packaging and shipping this high density product.

Nevertheless improvements are needed, especially in storage stability, if the industry is to develop to the level that is possible. Even very minor differences in quality of this bland product will be important in determining the level of consumption that is ultimately reached.

Fundamental research is especially needed. We must greatly increase our knowledge concerning the constituents of potatoes, and concerning the changes that can take place in these constituents during processing and subsequent storage. The results of such fundamental investigations will serve as a sound basis for continued technological developments—for potato granules and also for other potato products—and will help assure that potato granules will be of greatest possible value as an outlet for potatoes in the markets of the future.

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R. K. Eskew

Potato Flakes

Potato flakes is a term used to describe mashed potatoes which have been dehydrated on a drum drier by the process developed at the Eastern Utilization Research and Development Division of the Agricultural Research Service in Philadelphia. Drum drying of cooked potatoes for flour has been known for some 50 years. It was introduced into the United States from Germany shortly after World War I. Cooked potatoes have also been drum dried extensively in Germany for feed under government subsidy. Retention of individual cell structure is unimportant in these products. In contrast, if the dehydrated product is to be capable of reconstitution to an edible mash with a consistency equal to that of mash prepared from fresh potatoes the cells must remain largely unruptured. The release of free starch from broken cells contributes an undesirable pastiness. Cooke (1912) was one of the first investigators to recognize this principle.

BACKGROUND

More than a century ago a U. S. Patent was granted to Edwards (1845) for dehydrating mashed potatoes. Since then mashed potatoes have been dehydrated in many physical forms. Cooke (1912), Remmers (1918), Allen (1921), Stoddard (1922), Gano (1940), Nixon (1944), Kaufman *et al.* (1949), and others describe shreds or porous filaments. Heimerdinger (1926), Bowen (1931), Barker *et al.* (1943), Burton (1944), and Morris (1947), describe the production of a powdered mashed potato by spray drying. It was Bunimovitch and Faitelowitz (1936) who first reported that at a moisture content of about 40 per cent potatoes could be reduced to a moist friable powder permitting drying to a granular product without excessive cell rupture. Various methods for this first stage of drying (from 80 per cent to 40 or 50 per cent moisture) were subsequently proposed.

EARLY DRUM DRYING STUDIES

Of particular interest in connection with the flake process is the work of Jones and Greer (1940 and 1943), Barker (1941), and Barker *et al.*

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(1943). These investigators proposed the use of a drum drier to reduce the moisture content of mashed potato to a range between 40 and 65 per cent, followed by disintegration of the sheet and a final pneumatic drying step. Barker (1941) states that if moisture content is reduced to 45 per cent or lower, damage to cells may be found to occur, but that at a moisture content of 50 to 53 per cent no such damage is observed. Barker *et al.* (1943) investigated both a double drum drier and a single drum of the type used for making potato flour. They reported that the small rolls used for applying mash to the heated drum of the latter type damaged the potato cells; they further advised keeping drum temperatures below 266°F. The moist sheet was then held for two and one-half hours after which it became sufficiently friable to permit granulating by brushing through a sieve. Olson and Harrington (1955) used a small double drum drier for this partial drying and found it harmful to texture if temperatures above 212°F. were used.

In the foregoing work with drum driers the objective seemed invariably to have been the production of a granular product using drum drying only as a means of reducing the moisture to a point where granulation of the product became possible. It seems strange that nothing can be found in the literature prior to 1954 relative to drum drying mashed potatoes for food to a dryness suitable for storage and use.

The systematic study of the dehydration of mashed potatoes for food on drum driers was initiated by Cording *et al.* (1954). Their early work was done on a pilot plant double drum drier with six-inch diameter rolls. To obtain mash of good texture on reconstitution, it was necessary at that time to use potatoes of at least 20 per cent solids. After washing, peeling and trimming in the usual way, the potatoes were sliced in $^3/_4$-in. slabs and cooked in atmospheric steam for 12 to 15 minutes—a shorter cook than generally used for granules or flour. Mashing was effected in a planetary mixer as mashing rolls appeared to cause some cell rupture.

Double drum driers are not ordinarily used for materials with the physical properties of mashed potatoes. Feeding had to be accomplished by a continuous wiping action with a paddle to force the mash into the nip between the rolls and to continuously expose fresh mash to the heated drums thereby avoiding "case hardening" the surface of the mash. Dilution to a fluid consistency, permitting a more conventional method of application, damaged the cells.

Drum clearance was found to be of great importance. Clearances below 0.007 in. caused excessive cell rupture and yielded a pasty product, according to Willard and Cording (1957). Using a clearance of 0.013 in. the product was incompletely dried in one stage at a drum temperature of 289°F. but on further drying in air was reduced to a moisture content

satisfactory for storage and for rapid rehydration to good mashed potatoes. With a clearance of 0.17 in. the product could be dried satisfactorily in a second stage but did not rehydrate to a mashed potato of suitable texture. Cording *et al.* (1954) found that depending somewhat on drum speed, temperatures as high as 335°F. could be used without scorching the product or inducing pastiness. Cording and Willard (1956) found that dilution of the mash made from very high solids potatoes, e.g. 24 per cent dry matter, to reduce solids to between 20 and 22 per cent, improved adhesion to the drum and gave a product having four per cent or lower moisture.

Although subsequent work by the same investigators showed a single drum drier of the type used for flour to be much superior to a double drum unit for dehydrating mashed potatoes, these early studies established at least two important principles relative to drum drying; (1) mashed potatoes can be dried to low moisture in one stage on a drum drier to give a product which yields on reconstitution a mash of good texture and flavor, and (2) the moisture content of the mash should be kept between 78 and 80 per cent in order to achieve good adhesion to the drum and low final moisture without scorching.

INFLUENCE OF COOKING ON TEXTURE

In order to rehydrate to an acceptable product, a dehydrated mashed potato must yield on reconstitution a mash which has substantially the same texture or "feel in the mouth" as a freshly prepared mash. Naturally the latter will vary greatly depending on the variety of potato used and the method of preparation. In general, high solids varieties such as Russet Burbank, especially when grown in the Rocky Mountain area, give a mealy somewhat fluffy mash: lower solids varieties, for example Katahdins, give a smoother mash. Regional texture preferences correspond roughly to the type of mash obtainable from varieties grown in those regions.

Preference may be for a mealy or a creamy mash, a thick or thin consistency or for a particular flavor; but seldom if ever for pasty texture such as results from too much free starch. Pastiness may result not only from free starch but from too low solids in the potatoes, from immaturity at harvest and also from the cooking procedure used.

Reeve (1954) studied the effects of different heat treatments on the gelation of starch in the potato cell and the resultant effect on texture. Cording *et al.* (1955) and Cording and Willard (1957) found that precooking of raw potato slices between 140° and 180°F. prior to cooking at higher temperatures until soft, enabled the making of a flake yielding a good texture from potatoes as low as 18.5 per cent solids (ca. 1.073 specific

gravity). By varying the time and temperature of precooking, the texture of the reconstituted mash from Idaho grown Russet Burbanks could be varied over a wide range. It could be made "pasty," "desirably mealy" or "unpleasantly sandy." The most desirable precooking conditions were found to be about 20 minutes at 160°F. Later work by the same authors showed these conditions to be satisfactory for some 14 potato varieties. The cooking time should be varied between 16 and 40 minutes in atmospheric steam; the lower solids varieties requiring the longer time. The use of precooking in potato flake manufacture will undoubtedly enable the production of flakes in the Midwestern and Eastern areas where some lower solids varieties are grown and where more potato processing would be desirable.

SELECTION OF RAW MATERIAL

To be suitable for flakes a potato should be of a variety which will yield a mash of good texture when made from the freshly cooked potato. Low solids potatoes of the type best for canning or salads are not suited for flakes. Similarly, types usually grown in the Southeast for the early market and harvested before maturity should not be used.

Reducing sugars should not exceed one per cent on the fresh basis at the time of processing. Varieties which recondition well throughout the season are thus desirable. Good flakes have been made at the Eastern Utilization Research and Development Division from individual lots of the following varieties grown in twelve states:

California–Kennebec, Russet Burbank, White Rose
Idaho–Russet Burbank
Maine–Cherokee (Presque Isle), Green Mountain, Katahdin, Kennebec, Russet Burbank
Maryland–Cobbler (Eastern Shore)
Michigan–Russet Rural, Sebago
Minnesota–Cobbler and Red Pontiac (Red River Valley)
Montana–Russet Burbank
North Dakota–Russet Burbank (Walhalla)
New York–Katahdin, Russet Burbank
Pennsylvania–Katahdin, Russet Rural
Washington–Russet Burbank
Wisconsin–Cobbler (Rhinelander), Russet Burbank (Antigo)

Cording *et al.* (1957) brine classified several varieties of field run potatoes into six fractions according to specific gravity and determined the proportions of the different fractions. Using Katahdins they showed that good flakes could be made from field run potatoes having an *average*

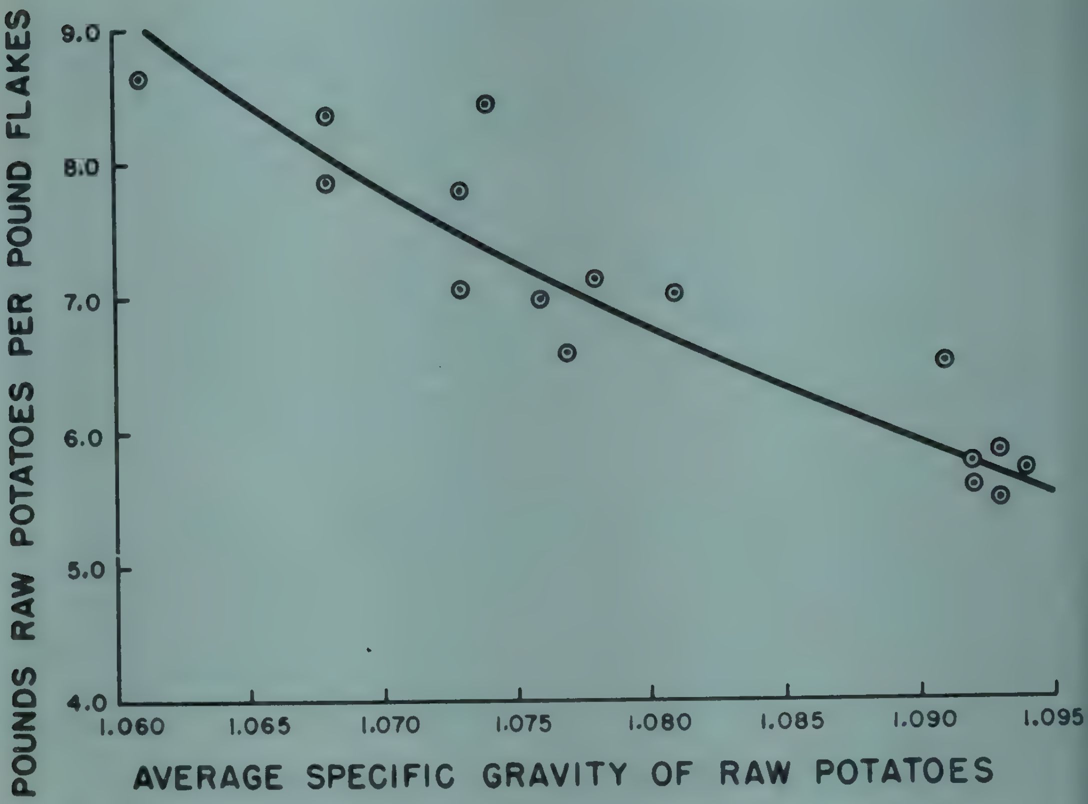

Fig. 76. Effect of Specific Gravity of Raw Potatoes on Yield of Flakes

specific gravity of 1.073 or higher. Batches having an average specific gravity of 1.070, 1.068 and 1.065 gave products of poor texture; however these three lots were upgraded to become suitable raw material by eliminating all fractions below 1.065. This entailed the grading out of from 23 per cent to 35 per cent by weight of the potatoes.

Product quality is, of course, not the only consideration in selecting raw material. Yield is of prime importance and is markedly influenced by the solids content of the potato, as shown in Fig. 76. These data were taken from pilot plant operations (Cording *et al.* 1957). They thus represent relative rather than the absolute yields to be expected in large scale production.

POTATO FLAKE PROCESS

The manufacture of potato flakes may be thought of as becoming commercially feasible with the adaptation of the single drum drier to their production. Eskew *et al.* (1956) operated an integrated pilot plant and determined the basic engineering data from which they prepared cost estimates. They showed that potato flakes could be produced commercially at a cost enabling their profitable sale at a price equal to or lower

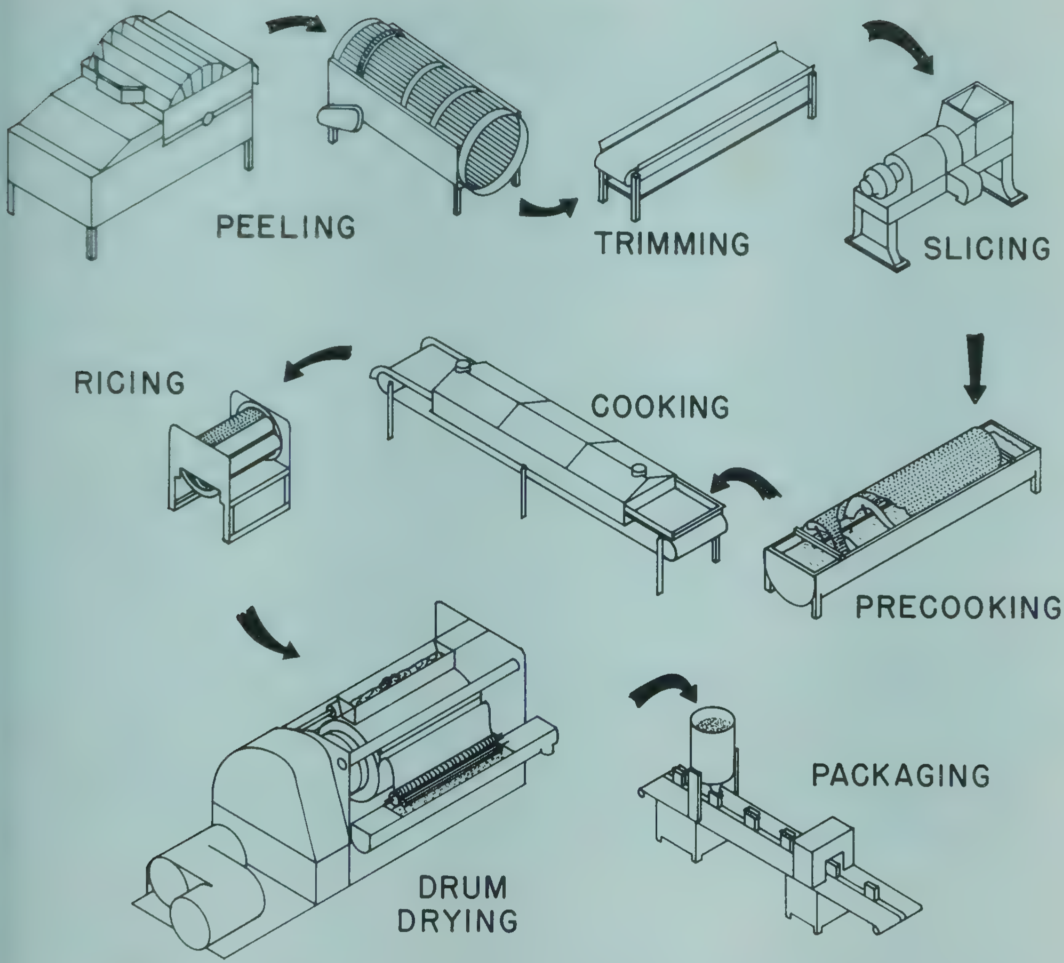

Fig. 77. Diagrammatic Sketch of the Potato Flake Process

than the then current price of competitive forms of dehydrated mashed potatoes.

The process is generally carried out commercially as shown in Fig. 77. Pictures of laboratory operations for preparing potato flakes have been used due to difficulties in obtaining photographs of commercial operations.

Preparation and Cooking

Potatoes after washing are lye- or steam-peeled, trimmed, sliced to slabs approximately one-half inch in thickness, and then precooked for 20 minutes in water at 160°F. They are then cooked in atmospheric steam until just soft enough to rice. It generally requires 20 minutes for high solids starchy types and about 40 minutes for Katahdins and lower solids varieties. Overcooking is harmful to texture.

Ricing

Various methods of mashing were tried including smooth rolls run at the same speed and a tapered screw in a perforated cone. The rolls did

not consistently accept the slices since they were slightly undercooked and slippery. Both the rolls and the screw caused cell rupture. A ricer was designed by Hyde and Cording (1958) which significantly reduced this. Mullins *et al.* (1955) have used "blue value" as a measure of free starch released from broken cells. With this method, the blue color developed on addition of iodine is measured colorimetrically. Mash made with the screw had a "blue value" of about 150; that made with the ricer, about 75. The ricer consists of a rotating perforated cylinder ($^{17}/_{64}$ in. diam. holes) on the outer surface of which two small solid rolls are driven at the same peripheral speed as the drum. The clearance between the drum and the first roll is just sufficient to permit acceptance of the cooked slices and to crush them lightly. The second roll is set close enough to force the potatoes through the perforations. A ribbon screw inside the perforated cylinder and rotating in the opposite direction discharges the product at one end. The ricer is shown in Figure 78.

Additives

Additives are preferably introduced before drying to improve flavor stability and texture. Amounts to be added per ton of mash are shown in Table 40.

TABLE 40

AMOUNT OF ADDITIVES USED PER TON OF MASHED POTATOES

Additives	Gm. per 2000 Lbs. Mashed Potato	Per cent Additive, Based on Solids in Mash (Assuming 21.5 Per cent Solids)
Glycerol monopalmitate	200	0.10
Tenox VI[1]	150	0.077
Skim milk solids	400	0.20
Sodium sulfite	120	400–500 p.p.m. sulfite in wet
Sodium bisulfite	40	mash

[1] Reference to a specific product does not imply an endorsement by the U. S. Dept. Agr. over others not mentioned.

Obviously the amount of SO_2 in the dried product is much lower than that shown in the table; generally 150–200 p.p.m. depending on the drying conditions. Glycerol monopalmitate is added to improve the texture of the reconstituted mash; especially when near-boiling liquids are used. It may contribute a slight grayish cast which is overcome by adding a small amount of skim milk solids, incorporated before drying. It has been suggested that all the milk that would normally be added on reconstitution might be added before drying, thus requiring only hot water at time of use. However, large amounts of milk contribute a glazed appearance and a cheese-like flavor to the reconstituted mash. The sulfite prevents changes during processing and probably improves shelf-

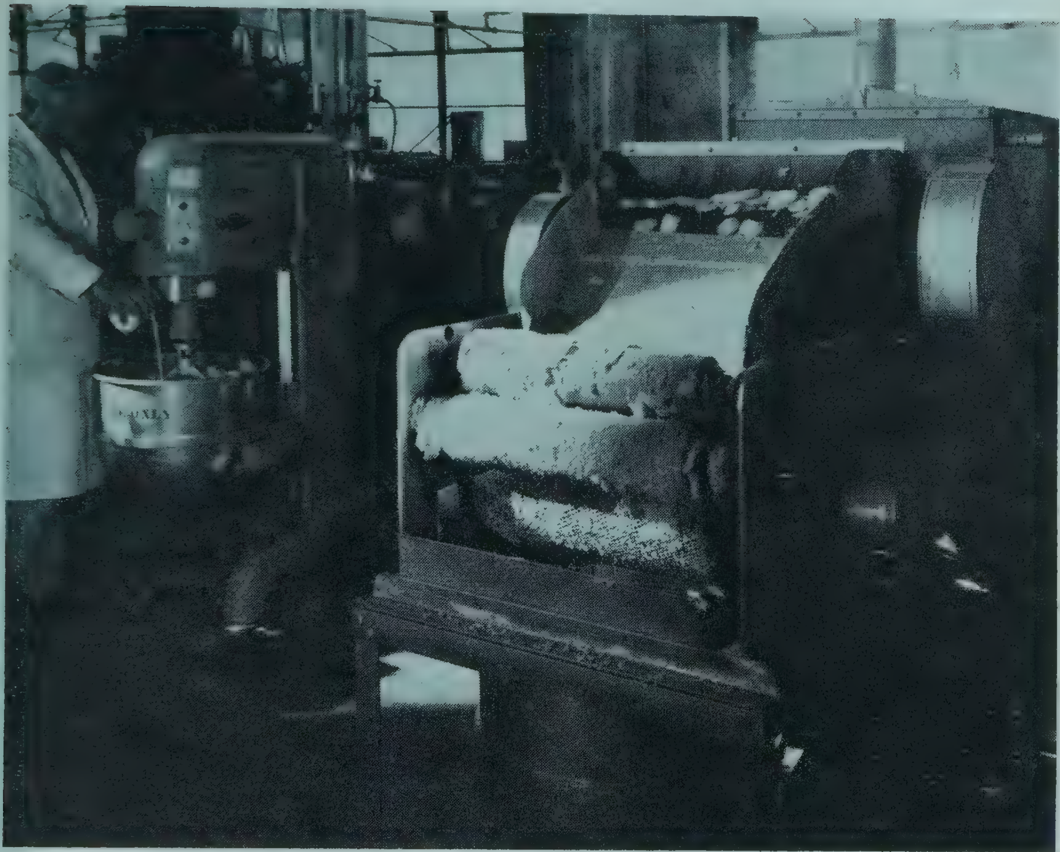

FIG. 78. DISCHARGE END OF COOKER SHOWING RICING AND INCORPORATION OF ADDITIVES

life. Tenox VI[1] provides protection against oxidative rancidity. The additives may be either sprayed on the slabs as they pass over the surface of the ricer or poured into the mash if it is mixed before drying. Mixing, like all the manipulations during processing, should be as gentle as possible to avoid cell rupture.

Drying

Drying can best be done on a single drum drier of the type commonly used in making potato flour. The mash is fed to the top surface of the drum by a two-way ribbon screw rotating in the opposite direction from the drum. Small diameter unheated rolls (Fig. 79) progressively apply fresh mash to that already partially dried, thus filling interstices and building up a dense sheet. The peripheral speed of the rolls is the same as that of the drum and if their clearance from the drum is kept at about one-quarter of an inch, there is no apparent cell damage.

Since the holes in the ricer are comparatively large and cooking is kept

[1] Reference to a specific product does not imply an endorsement by the U. S. Dept. Agr. over others not mentioned.

FIG. 79. WET MASH SIDE OF SINGLE DRUM DRIER SHOWING APPLICATOR ROLLS

to the minimum consistent with avoidance of cell damage during ricing, the mash as fed to the drier will contain numerous small translucent pieces of unmashed potato. Occasionally some of these will appear as small peaks on the sheet as it leaves the last applicator roll. These are conveniently ironed into the sheet by a Teflon[1] covered steel roll located under the belly of the drum and driven at the same surface speed as the drum, at a clearance of about 0.007 in. from it.

A doctor knife removes the dried sheet, although in most cases when a good dense sheet is being made, it peels away from the drum just ahead of the knife leaving the surface quite clean. The sheet is made into thin $^1/_2$-in. flakes by a slitting roll followed by a roll which cuts the strips transversely. This is shown in Fig. 80. Both rolls press firmly against the surface of a rubber covered roll. The amount of fines produced is so small as to not require screening of the product. Thus, the yield on drying is substantially 100 per cent of solids in the mash.

Of the various methods of drying mashed potatoes drum drying next to spray drying, is by far the most rapid. A mash of 80 per cent moisture is reduced to five per cent or less in approximately 20 seconds. More-

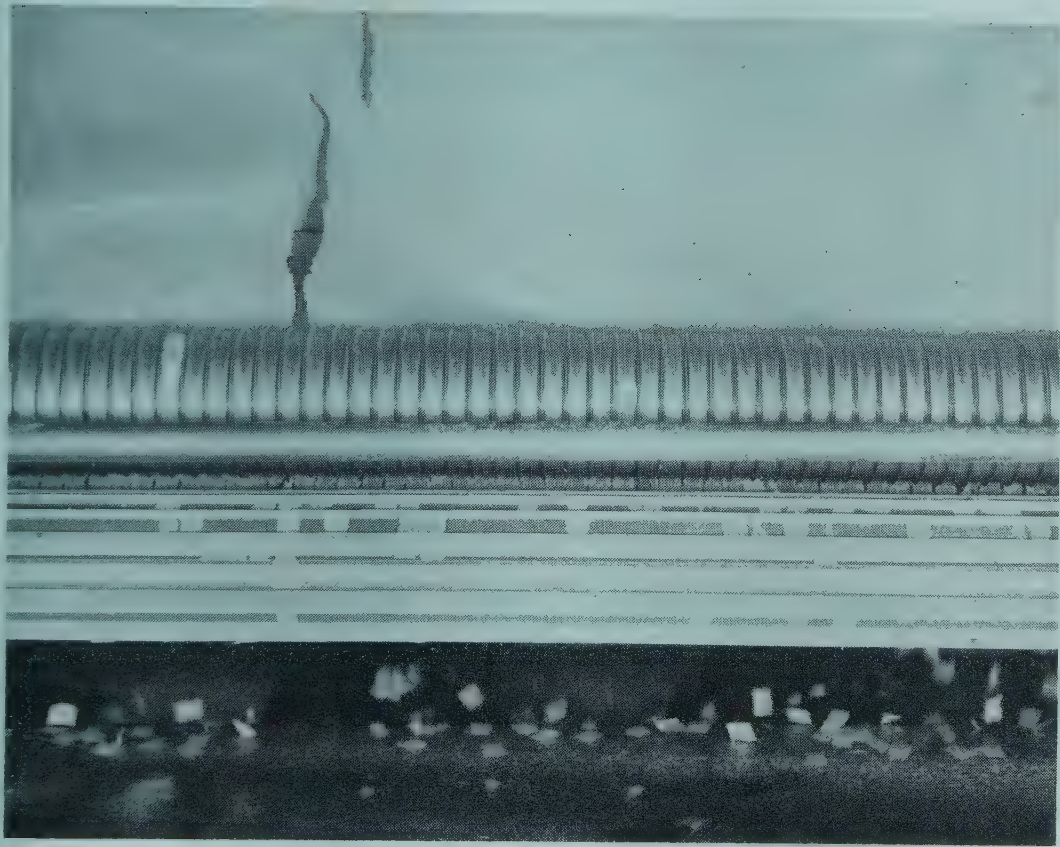

FIG. 80. DRIED SHEET BEING CUT INTO FLAKES ON DISCHARGE SIDE OF DRUM DRIER

over, this is accomplished in a partial blanket of steam which reduces the opportunity for oxidative changes during drying. These factors undoubtedly contribute to the good flavor of mash reconstituted from potato flakes.

BASIC DATA FOR EFFICIENT OPERATION OF THE DRUM DRIER

Drum drying of cooked potatoes is a comparatively simple operation, but to carry it out at a high production rate with good thermal efficiency and at the same time obtain a dense sheet without cell damage, requires careful control of a number of factors. Cording *et al.* (1957) have studied the effect of drum speed and solids content of the potato on production rate, sheet density and product moisture. Fig. 81 shows how the product rate increases with both solids in the potato and drum speed. Although not shown in the graph, increase in solids content above 22 per cent may reduce output because the fluffy character of the resulting mash prevents good adherence to the roll. Experience has shown that a very high solids mash should be diluted to about 21 to 22 per cent solids to obtain good contact between sheet and drum and to form a dense sheet. Also, as shown in Fig. 82, high product rates, i.e., high drum speed, are accom-

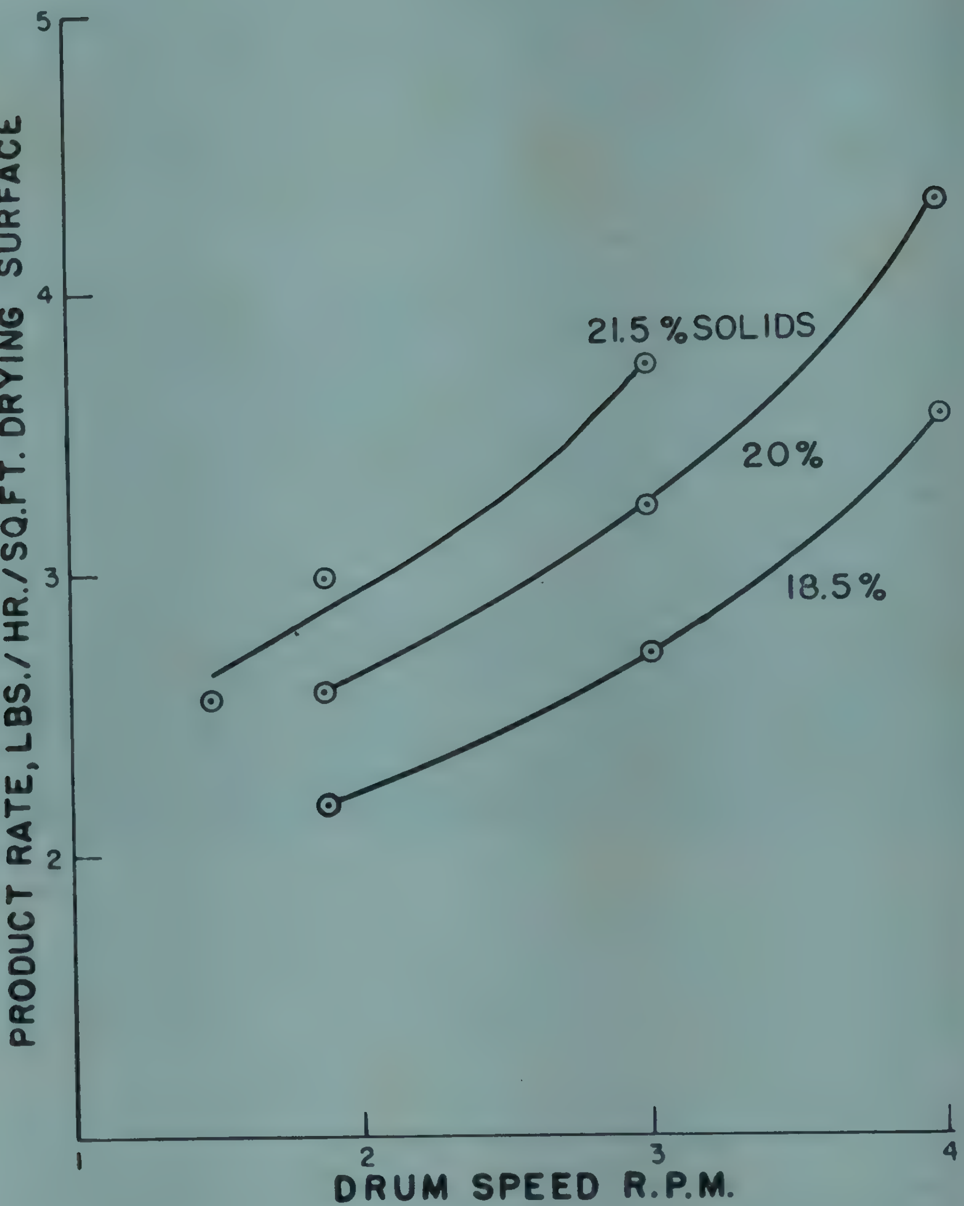

FIG. 81. EFFECT OF DRUM SPEED AND SOLIDS CONTENT OF POTATOES ON POTATO FLAKE PRODUCTION RATE

plished at the expense of sheet density. This is very important because low density means higher packaging costs and may also cause too rapid absorption of liquid on reconstitution. Very rapid rehydration may result in cell rupture and pastiness.

One of the advantages of drum drying is that it yields a product of low moisture, e.g. 4.5 per cent, in a single stage. At this moisture content, the browning type of flavor change which develops during storage takes place much more slowly than at higher moisture content. Fig. 83

shows that at drum speeds above 2 r.p.m. product moisture rises. It might appear that moisture would decrease at speeds below 2 r.p.m.; however, it tends to rise. The very rapid increase in sheet density at these slow speeds causes the sheet to become overly dried on its inner surface and to separate from the drum before diffusion of the moisture

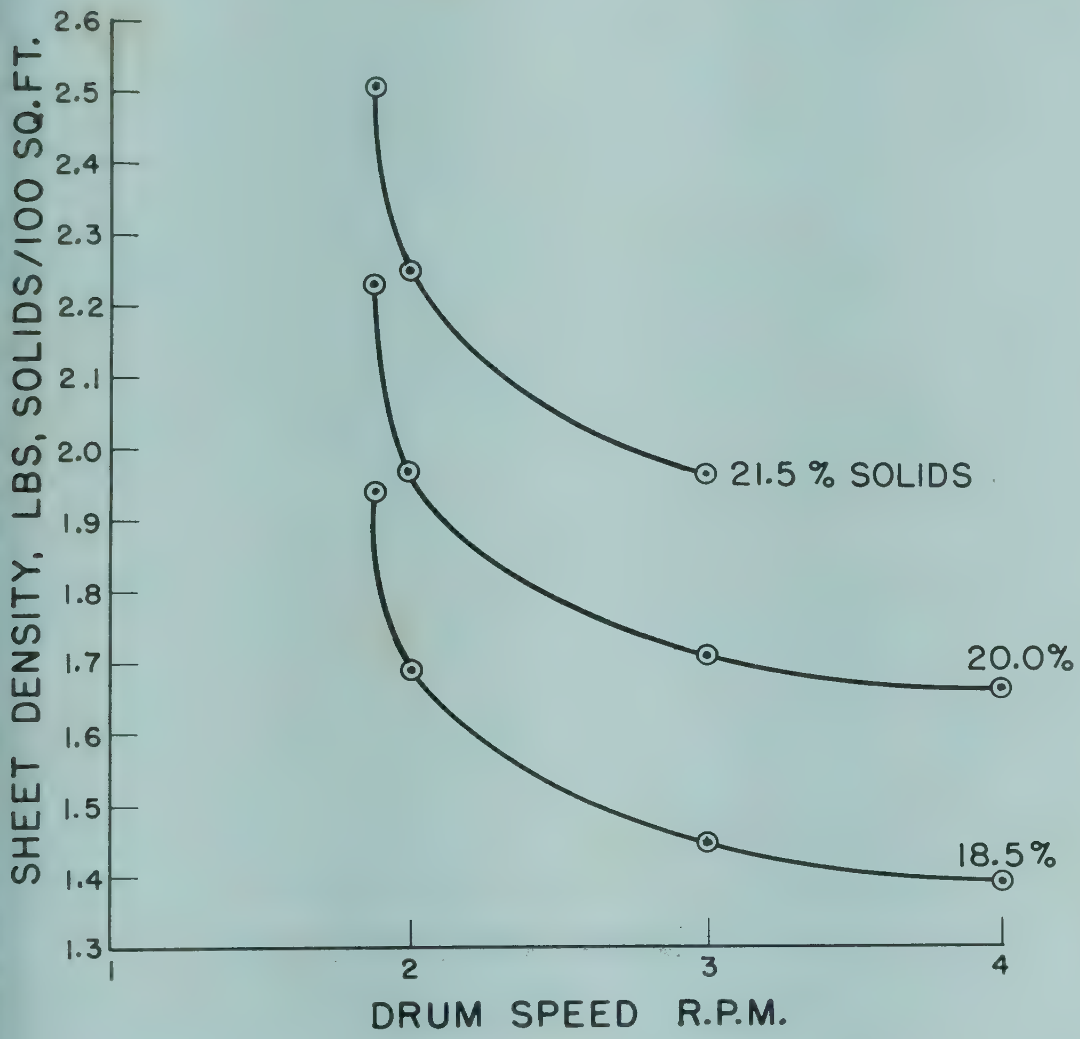

FIG. 82. EFFECT OF DRUM SPEED ON POTATO FLAKE SHEET DENSITY

can take place. An increase in steam pressure above 80 lbs. per sq. in. may also cause overdrying on the inner sheet surface to such an extent that the sheet may fall to the floor before completing its travel. The most favorable drying conditions are generally as follows: Solids in the mash between 20 and 22 per cent, steam pressure 75 to 80 lbs. per sq. in., drum speed 2 r.p.m. This should give a dense sheet having between 4.5 and 5 per cent moisture.

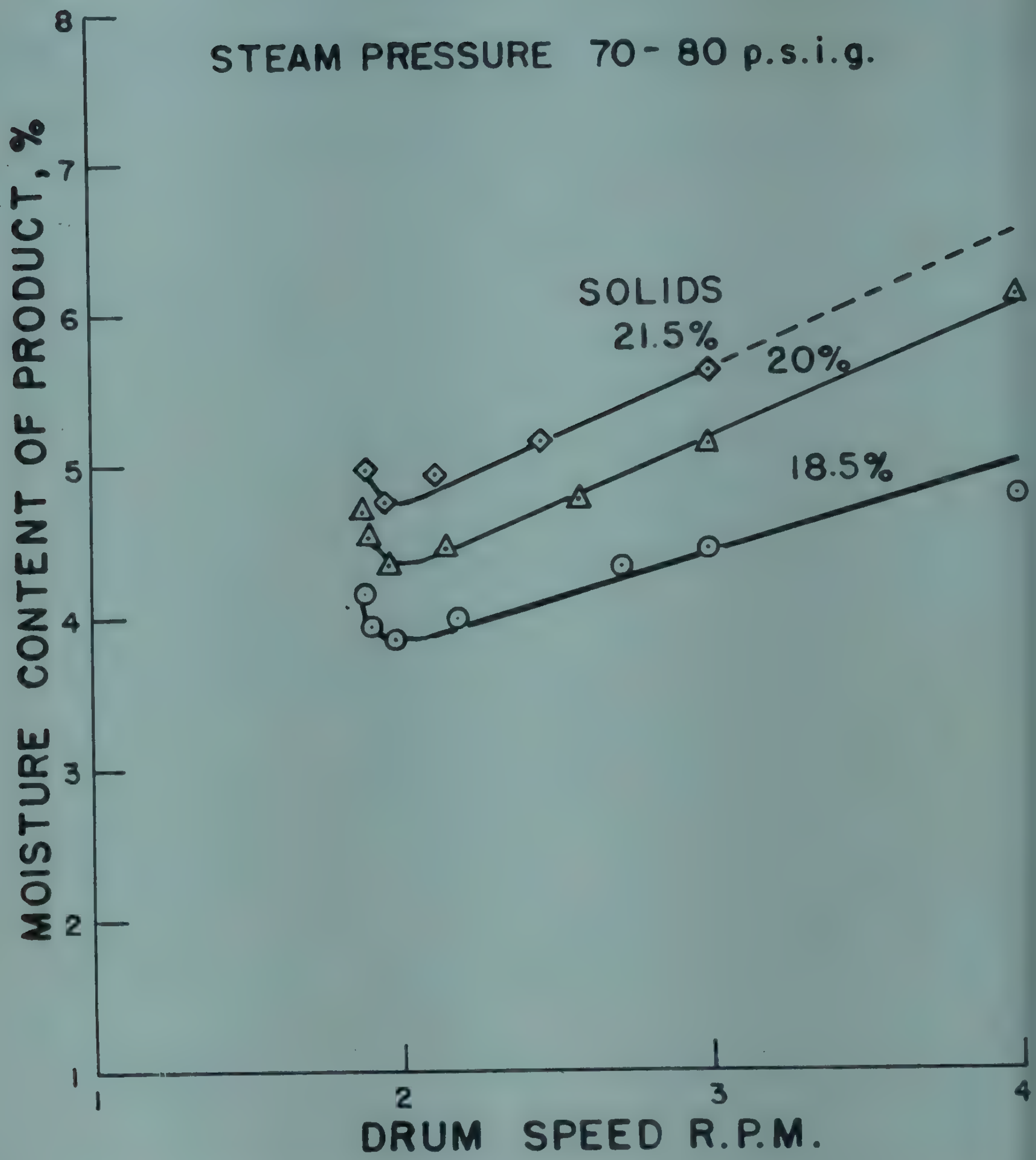

Fig. 83 Effect of Drum Speed on Moisture Content of Potato Flakes

PACKAGING AND STORAGE LIFE

Flakes are normally dried to a moisture level (ca. 4.5 per cent) at which any flavor deterioration results principally from oxidation. This can be greatly retarded by partial exclusion of air or by the use of an antioxidant. Obviously, the package should afford an effective moisture barrier and must be rigid enough to prevent crushing. It should also be opaque as light greatly accelerates development of rancidity.

In tests made at the Eastern Utilization Research and Development Division potato flakes made from Idaho grown Russet Burbank potatoes,

nitrogen packed (3.5 per cent oxygen) in a tin can, remained substantially unchanged in flavor for more than a year at 73°F. These flakes had 218 p.p.m. of Tenox VI[1] added to the mash before drying. However it is doubtful that more than ten per cent of this carries through to the dried product. When nitrogen was used without antioxidant, or when the flakes were air-packed and the antioxidant was used, storage life was reduced. However, after six months the flavor was considered at least as good as that of other forms of dehydrated mashed potatoes on the market.

No systematic storage data are available on flakes made from other potato varieties but spot checks on flakes from Katahdin and Russet Burbank potatoes grown in Maine show keeping properties to be quite similar to those reported above.

It is costly to pack a product such as flakes in an inert gas. Research has thus been directed toward increasing their density. The flakes first produced on a double drum drier by Cording *et al.* (1954) weighed only about 7 lbs. per cu. ft. Improvements in technique, especially the use of a single drum drier, raised this to 14 lbs. per cu. ft. More recently flakes weighing as much as 27 lbs. per cu. ft. have been produced experimentally by Cording and co-workers.

PRODUCT EVALUATION

During the summer of 1956 a market test on potato flakes was made in the tri-city area of Binghamton, Endicott, and Johnson City, New York. The results are given in detail by Dwoskin and Jacobs (1957). This was a cooperative undertaking among various agencies in Maine, the Agricultural Research Service and the Agricultural Marketing Service. A carload of Russet Burbank potatoes grown in Maine was made into flakes in the Philadelphia pilot plant. They were air-packaged in four-serving packages consisting of a cardboard box with a heat-sealed liner made from a laminate of polyethylene, kraft paper and aluminum foil. These were sold in chain and independent stores in the test area. Nine hundred cases (24 boxes per case, 4-servings per box) equivalent to 28,000-lbs. of fresh potatoes were sold in a 5-week period. Nine out of ten homemakers who bought potato flakes expressed general satisfaction with the product. About 60 per cent made repeat purchases and some 50 per cent of the one-time buyers indicated that they were potential repeat purchasers. The overall results showed a ready consumer acceptance of the product.

Greig and Larzelere (1957) conducted consumer taste panels from which they concluded that consumers had a highly significant preference for mashed potatoes from flakes over those made from other commercial forms of dehydrated mashed potatoes.

Greig (1957) reports the reaction of buyers for 164 establishments in the restaurant, hotel and institutional trade to whom potato flakes were demonstrated. He states in part, ". . . Eighty-three per cent of the buyers who had tasted other forms of dehydrated mashed potatoes indicated that potato flake quality was better. . . ." ". . . Ninety-one per cent of the buyers indicated that flakes would be of satisfactory quality for use in their establishment. . . ." ". . . Fifteen per cent of the total buyers interviewed indicated they would use more mashed potatoes in their establishments if this product (flakes) was available commercially. . . ."

FUTURE

As of January 1958 six companies had signified their intention of producing potato flakes commercially and were installing the necessary equipment. These were in widely scattered areas: Maine, New York, Idaho, Oregon and Southern California. Factory scale operations in at least two plants had already yielded a product fully equal in quality to that produced under carefully controlled pilot plant conditions.

There is good reason to believe that potato flakes will soon be found on market shelves and, because of their quality and convenience, will help increase the consumption of potatoes.

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Ray W. Kueneman

Dehydrated Diced Potatoes

BACKGROUND

The history of the production and utilization of dehydrated vegetables is somewhat unique inasmuch as developments in vegetable dehydration have been chronologically keyed to military conflicts. The Spanish found that the Incas of Peru had solved one of the most important logistic problems of military campaigns by use of a concentrated potato product called "chuno" which enabled them to feed their military forces successfully. Succeeding events in world history have periodically revived interest in attempts to produce acceptable dehydrated potato products to solve military feeding problems.

Dehydrated products were manufactured on a large scale for military purposes during World Wars I and II and attempts to market the product on civilian markets created flurries of interest at the end of each war. Despite avowed attempts by the industry to avoid the conditions following World War I, when an industry was created as a wartime expedient and disappeared about as quickly as it was started, much the same condition developed following World War II. The number of firms engaged in vegetable dehydration dwindled once again from over one hundred firms with active interests to a very few. In 1944, there were 111 dehydrated potato processors listed in the directory of the National Dehydrators Association. Today there are about ten firms actually engaged in dehydrated potato production and two of these are newcomers. It is also interesting to note that only four firms are engaged in production of dehydrated diced potatoes today while the major part of the productive capacity during World War II was devoted to diced potatoes and the closely related Julienne strip. Production of dehydrated dice is now approaching 20,000,000 lbs. per year.

Dehydrated diced potatoes are becoming increasingly important in today's food industry. They afford manufacturers of food products and other users of potatoes, the superior quality of Russet Burbank and other varieties of potatoes having high specific gravity. Dehydrated diced potatoes of uniformly high quality are available throughout the entire year in a number of sizes and shapes. They eliminate the need for high cost labor and equipment required for peeling, inspecting and slicing.

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Their usefulness in military feeding has been adequately demonstrated.

While drying *per se* is one of the oldest methods for food preservation, the acceptability of dried vegetables including potatoes has been low until the last few years. Improved technology, production methods and machinery have revolutionized the performance and quality of the product to such an extent that a stable and expanding industry has developed.

Dehydrated potato dice are used in a number of processed foods. Defense agencies procure substantial amounts for their uses. Institutions are finding them useful in meeting their requirements for potatoes and, to a limited extent, they are being packaged in small units for sale to the retail trade. One of their principal outlets is for use in canned meats with canned corned beef utilizing a large part of the dehydrated dice being produced. In canned corned beef the dice may be rehydrated and mixed with the beef before canning, or they may be added dry and allowed to rehydrate during the retorting of the canned product. For products such as frozen meat pies or potato salad, the pieces must be completely rehydrated with a minimum amount of disintegration before mixing with the other ingredients as these products are not retorted. Diced potatoes procured for most military uses are cut quite thin so as to reduce rehydration and cooking time. Where used in mess halls and field operations, they are served as buttered dice, hashed brown, or even mashed.

RAW MATERIAL FOR DEHYDRATED DICED POTATOES

There are a number of significant factors to be considered in the selection of suitable raw material. During World War II there were more plants in the U. S. engaged in the production of dehydrated potatoes than of any other vegetable product. As a consequence, there was in effect a massive crash program that tested on a production basis every principal variety and growing area in the country. On the basis of the results obtained, measured in terms of costs of production, quality and performance of the finished product, freedom from processing problems inherently due to the variety or locality in which the crop was grown, availability, and length of harvest season, definite recommendations can be made for selection of potatoes for dehydration.

Color

In view of the many uses for dehydrated potato dice, color is an important factor in determining raw material suitability. There is a decided preference among consumers in the United States for potatoes with white flesh color as compared to the more yellow pigmented or cream-colored varieties often found in European markets, and in limited areas of this

country. Some varieties of potatoes are inherently lighter and brighter in color than others, although varietal differences may be greatly influenced by growing locality and by cultural practices.

There are other raw material problems to be considered as well. One of the most serious is a graying or darkening that occurs in some lots of potatoes during the successive steps in the production of dehydrated potatoes. This discoloration affects the product in both dry and reconstituted form. Some lots of potatoes are so seriously affected that even with all of the remedial treatments listed below, they will not yield a satisfactory dehydrated product. Others are less affected, but even so, are very difficult to process without rather severe discoloration.

Much difficulty from this source was experienced in the procurement of dehydrated potatoes for the armed forces during World War II. As a result of extensive research sponsored by the Office of the Quartermaster General, it was established that enzymatic oxidation of monohydric tyrosine is very frequently the cause of this discoloration (Highlands *et al.* 1947). Reaction of the tyrosine with oxygen of the atmosphere is catalyzed by the enzyme tyrosinase. A pinking of cut surfaces of the potatoes when exposed to the atmosphere is usually the first manifestation of discoloration. The color then progresses through reddish-brown to an unsightly gray in the dehydrated product. Pinking is known to be the first stage of the tyrosinase-catalyzed oxidation of tyrosine.

Sometimes, however, the color seems to skip through the intermediate pink and brownish stages, and to be gray when it first appears. In this case it is possible that some reaction other than the tyrosine-tyrosinase oxidation is occurring. Graying occurs on dehydrating potatoes that would undergo after-cooking darkening when boiled. There is lack of agreement as to the mechanism of after-cooking darkening. It has been considered by many to be enzymatic in nature, but recent evidence suggests that it may result from oxidation of complexes between ferrous iron salts and o-diphenols such as chlorogenic and caffeic acids (Kiermeir and Rickerl 1955). In any case, oxidation by atmospheric oxygen is involved in the graying that occurs in dehydrated potatoes, and iron salts greatly increase the discoloration (see also p. 29).

The nature of after-cooking darkening, and that of the usual enzymatic discoloration that occurs at cut surfaces of potatoes, are further discussed elsewhere in this book. Comprehensive surveys of the literature on after-cooking darkening have been published by Yanovsky (1955) and Smith (1957; see also p. 28). Fortunately, some varieties of potatoes in some growing areas are singularly free of graying during dehydration. Experience has shown that potatoes grown west of the Continental Divide have a very low graying tendency. This factor among others accounts

for survival of the existing potato dehydration plants which are largely located in the West.

Most common commercial varieties can be classified into groups showing consistent differences in the rate and degree of discoloration in sound material grown under uniform conditions. Climatic and seasonal variations affect formation of compounds involved in the darkening. Temperature of soil during harvesting can also be a factor, lower soil temperatures resulting in increased discoloration. The problem is encountered more often during the middle and late storage season than it is shortly after harvest.

Potatoes from certain growing areas and varieties that are susceptible to discoloration should be avoided, since many years of experience have shown that the better the raw material, the better the finished product. But if the problem is encountered, there are a number of measures that can be instituted to help control it.

A tempering period of 2 or 3 days at 60° to 70°F., after the potatoes are removed from storage but before they are processed, is often helpful. Preheating the potatoes in water for 3 or 4 minutes at temperatures above 165°F. helps reduce the amount of discoloration.

Peeling mechanisms involving the use of heat such as steam or lye peeling often accentuate the problem. The reactants in the darkening system appear to be more concentrated in the peripheral area of the potato, especially around the vascular bundles, than in other parts of the tuber. The diminishing temperature gradient resulting from the peeling operation very often penetrates to this area, providing optimum thermal conditions for the enzyme system to reach a condition of accelerated activity. Under these conditions, cutting of the potato either during dicing or trimming makes possible access of enough atmospheric oxygen to promote this practically irreversible reaction, and results in a finished product with a gray cast or even a mottled appearance. The amount of discoloration increases with extent of exposure to the atmosphere.

As a consequence, reduction of exposure of the peeled potatoes to the atmosphere is very helpful in minimizing discoloration. This can be accomplished by spraying or dipping in water, and preventing undue delays in conveying by eliminating hang-up points and excessive recirculation on trim tables. In any operation, these measures should be given a great deal of care and attention. They are absolutely essential where the raw material has an appreciable tendency to discolor. With potatoes having a greater discoloration tendency, some further protection can be obtained by keeping the surfaces of the potatoes wet with a solution of any of a number of reducing compounds such as sulfur dioxide and sulfite salts. Solutions of citric, phosphoric and tartaric acids have also

been helpful. An alkaline substrate, such as may be left by improper washing following lye peeling, accelerates the discoloration.

The following references are given for those seeking further review of this problem: Smith and Kelly (1944), Tobin (1943), Dawson (1945), Nelson (1945), Wallerstein (1945), Highlands *et al.* (1947), Mullins *et al.* (1953), Robertson and Smith (1931), Tottingham *et al.* (1936 and 1939), and Ross and Tottingham (1938).

Color of the finished product in either dry form or when reconstituted immediately after processing or after storage, may also be greatly affected by a non-enzymatic discoloration caused by the "Maillard or browning reaction." This is evidenced by the development of dark yellow to reddish brown colors in the dice. Practically all processed foods are affected by non-enzymatic browning. In some instances it is deliberately employed to produce a desired brown color such as in the case of syrups and fried foods, but in other instances it presents a major problem in obtaining the desired storage life of the finished product.

The reaction essentially involves inter-relationships of protein, carbohydrates, pH, moisture, temperature and time. In the case of dehydrated potatoes there is a reaction between amino acids and sugars which can take place both during dehydration and during storage of the finished product. The manifestations in dehydrated potato dice are reddish brown discolored pieces in the dry state and dark discolored soggy brown centers in the reconstituted state. It is a limiting factor in determining maximum piece size and drying rate. In storage, dehydrated diced potatoes tend to develop a reddish-brown discoloration with the production of CO_2 and bitter off-flavors. One of the important considerations involved in the production of high quality dehydrated diced potatoes is that of obtaining a product free from these degradation products and which will be resistant to non-enzymatic browning in storage.

Dehydrated potatoes should be prepared from raw material that is relatively low in reducing sugar content if the product is to be free from non-enzymatic discoloration when first produced and is to remain reasonably so in storage. Mature potatoes at normal harvest time are relatively low in reducing sugar content, usually less than one per cent of the dry matter in the case of Idaho Russet Burbank potatoes. In the principal late potato growing areas such as Maine, Idaho, and the Red River Valley, potatoes are harvested in September and October and stored until as late as June. The several months of storage that follow harvest can be very critical as far as dehydration is concerned. Since most growers' experience is related to storage of potatoes for fresh market shipment, they desire to hold them at as low a temperature as possible without frost damage. These low storage temperatures, often 32° to 36°F., lead to the ac-

TABLE 41

GROUPING OF POTATO VARIETIES ON BASIS OF TENDENCY TO DEVELOP REDUCING SUGARS DURING LOW TEMPERATURE STORAGE[1]

High	Medium	Low
Green Mountain	Early Ohio	Sebago
Bliss Triumph	Katahdin	Russet Rural
Delaware	Early Rose	White Rural
Spaulding Rose	Irish Cobbler[2]	Rural New Yorker
Warba		Irish Cobbler[2]
Russet Burbank		Chippewa
		Sir Walter Raleigh

[1] From Ross *et al.* (1946).
[2] Irish Cobbler was rated as medium in New York, and low in Maine. This emphasizes the need for information about each variety in the different potato producing areas.

TABLE 42

EFFECTS OF VARIETY AND TEMPERATURE ON DEVELOPMENT OF REDUCING SUGARS[1] IN STORED POTATOES[2]

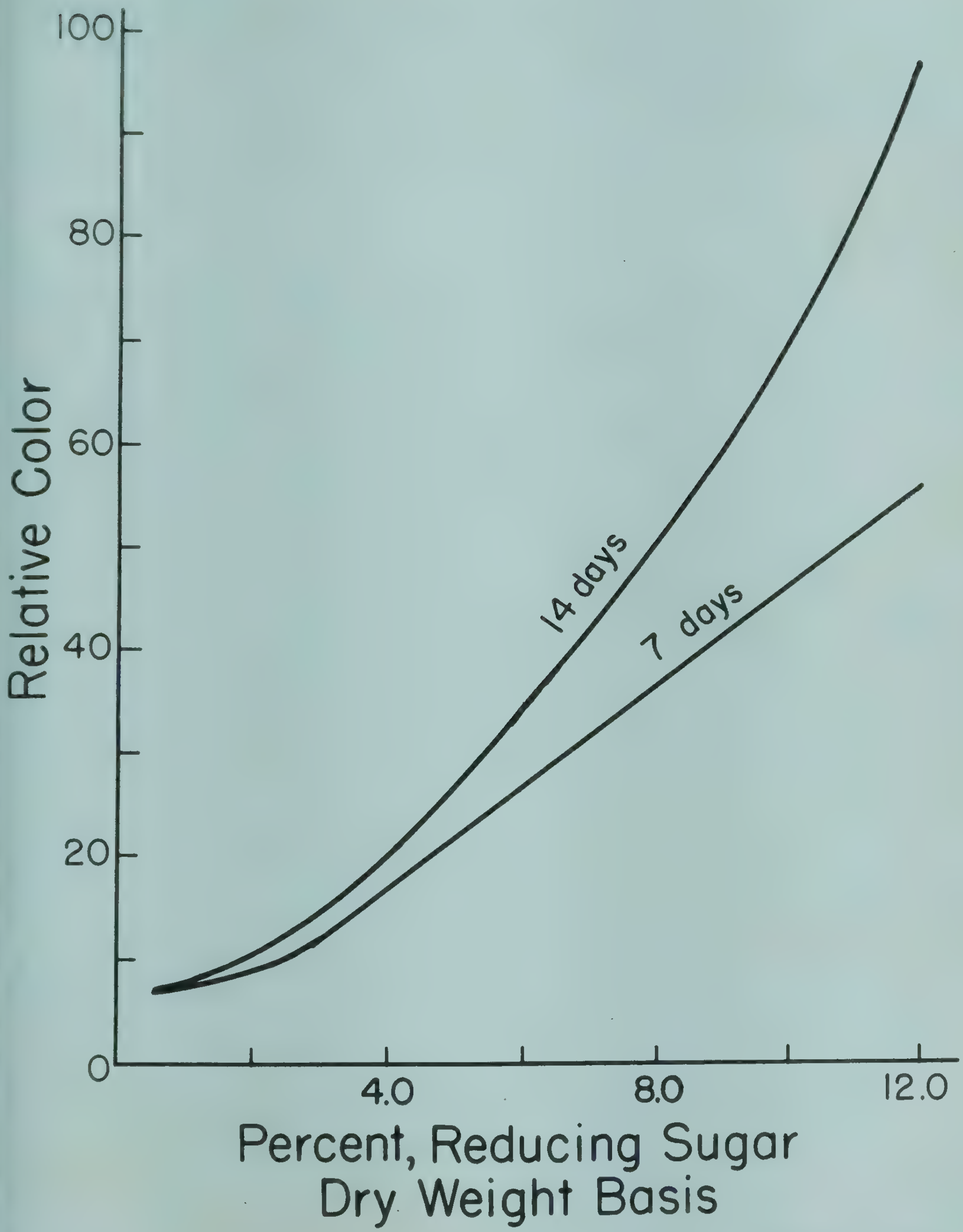
Temperature, °F.	Days in Storage	Green Mountain	Katahdin	Sebago
		Per cent	Per cent	Per cent
	0	3.8	1.4	1.3
70	30	1.7	0.7	0.7
50	50	3.9	1.5	1.3
	100	..	1.3	0.8
40	50	7.3	4.0	4.0
	100	6.1	4.6	4.0
	150	6.3	5.7	3.4
36	50	12.4	9.0	6.5
	100	9.4	9.4	7.8
	150	12.2	9.1	6.6

[1] Expressed as per cent of dry weight.
[2] From Ross *et al.* (1946).

cumulation of reducing sugars which may range up to 6 or 8 per cent of the dry weight or even higher. A convenient method of testing for reducing sugar content which also provides information on total solids was outlined by Ross *et al.* (1945) in a joint report by the Office of the Quartermaster General and also abstracted in Food Industries (Ross *et al.* 1946). Ross and his coworkers classified potato varieties into three groups according to their tendency to develop reducing sugars during low temperature storage, and described the effect of reducing sugars on scorching during drying and the relationship of reducing sugars to the storage life of the dehydrated product. In addition, the authors made recommendations for handling in order to obtain potatoes with low reducing sugar contents from harvest throughout the storage period.

Fig. 84 shows the effects of sugar content on the darkening of dehydrated diced potato during an accelerated storage test conducted at 130°F.

Table 41 classifies varieties according to their tendency to accumulate



From Ross et al. (1946)

FIG. 84. EFFECT OF REDUCING SUGAR CONTENT OF RAW TUBERS ON THE DISCOLORATION OF DEHYDRATED POTATOES AT 130°F.

The darkest sample was dark mahogany in color and was given an arbitrary value of 100. Only those with a relative color of 10 or less were considered edible.

reducing sugars during low temperature storage. It will be noted that the Russet Burbank which is used in producing a very high percentage of dehydrated potatoes is listed as a variety which accumulates high percentages of reducing sugars.

Table 42 shows amounts of reducing sugars that accumulate in potatoes stored at several temperatures. In addition to reducing sugars, substantial amounts of sucrose also accumulate.

Flavor and Odor

Flavor and odor of dehydrated diced potatoes should be fairly typical of the varietal characteristics of the potatoes processed. In view of the way that potatoes are used, it is not surprising that most of the varieties in common usage and acceptance in the United States today are quite bland. Off-flavors and -odors in dehydrated potatoes may develop from a variety of causes, most of which can be traced to raw material, processing methods or oxidative changes and products of the browning reaction which develop during storage.

Raw material can contribute a number of different off-flavors. One of the most common is a bitter flavor due to potatoes which have been exposed to light either during growing, harvesting or storage. The mechanism in all three instances is the same. When the tuber is exposed to light for an appreciable period of time, the skin responds with the production of the green pigment, chlorophyll. If exposure is prolonged this green color will extend into the flesh of the tuber. A tuber that has been materially affected in this manner, when cut, will show a gradient of green through yellow to the typical white flesh color. Accompanying chlorophyll formation, there is also production of solanine, a bitter glucoside. In the early stages of "light greening" the bitter flavor may be localized around the area affected by the color change but in advanced stages, it is present throughout the potato rendering it unfit for consumption in any form. Raw material showing major discoloration from this source should not be used.

Another off-flavor directly attributable to raw material which has occurred in recent years is a stale, musty, disagreeable flavor due to the application of benzenehexachloride to the soil for wire worm control. Since experiments have shown that this compound may affect the soil for several years, precautions should be taken to avoid procurement of raw material grown in fields treated with this compound. These flavors are not always evident when the product is first produced but may go through an induction period and become noticeable and objectionable only after several months of storage.

Other flavors that may appear from time to time are due to faulty stor-

age of raw material. These relate to potatoes stored with excessive field heat, unhealed bruises, pathological damage, and insufficient ventilation as well as rot, decay and microbiological fermentation products. Obviously potatoes containing high percentages of reducing sugar may be excessively sweet even if they are processed and stored under carefully regulated conditions to minimize non-enzymatic browning.

Texture and Product Performance

Raw material exerts a profound influence on texture and product performance as well as on costs of production. Numerous workers have pointed out that varieties of potatoes vary tremendously in specific gravity, a convenient index method for determining and expressing the total solids content. Heinze *et al.* (1952) have established that there is considerable variation in specific gravity and total solids content within a given variety grown in different locations and under varying conditions. They also point out that storage conditions have a significant influence on specific gravity and that variations in specific gravity are encountered even when the same variety is grown under the same conditions.

It has also been well established that cooking qualities are closely linked with specific gravity (Kunkel 1949; Batchelder 1949; Nutting 1949). In general, potatoes with high specific gravity have better cooking characteristics in that a greater range of types of cooked dishes may be prepared from them. Since dehydrated diced potatoes are a multiuse product, better product performance results when they are made from high-solids content potatoes. Wide variations in total solids between individual potatoes within a single lot will influence product performance, and for this reason, it is advantageous to know the range of distribution of total solids as well as the average value.

Potatoes with extremely high total solids content may tend to slough or mush excessively on reconstitution unless processing procedures are varied to suit these conditions. Potatoes with exceedingly low total solids content tend to be firmer and do not lend themselves well to end-use requirements where mealy characteristics are more desirable. Ross *et al.* (1945) described a simple and effective method for determining total solids. A copy of this is presented in the Appendix p. 465. However, to study distribution of total solids, the salt brine technique of Kunkel (1949) or a similar procedure should be used.

Production costs are markedly affected by total solids content of the raw material and can change the cost of finished product by ten per cent or even more in terms of the amount of raw material, direct labor, utilities and even the size of the plant required.

A comparison of possible recovery based on total solids alone is useful

TABLE 43

EFFECT OF SOLIDS CONTENT OF POTATOES ON THE RAW MATERIAL COSTS FOR DEHYDRATED POTATOES

	LOT A (18 Per cent Solids)	LOT B (22 Per cent Solids)
	Lbs.	Lbs.
Original ingoing weight	100.0	100.0
Preparation loss	25.0	25.0
Lbs. material to drier	75.0	75.0
Lbs. bone dry solids to drier	13.5	16.5
Lbs. total water	61.5	58.5
Lbs. yield dried to 6 per cent moisture	14.36	17.55
Drying ratio	7.0 to 1	5.7 to 1
Lbs. raw potatoes to produce 100 lbs. dry product at 6 per cent moisture	700	570
Value of raw potatoes used to produce 100 lbs. dry at 6 per cent if \$2.00/cwt. assumed	\$14.00	\$11.40
Difference is then \$2.60/100 lbs. dry for raw material		

Above figures must not be assumed to be actual ratios expected in operation since there are many other factors involved.

TABLE 44

REHYDRATION RATIOS VS. COEFFICIENTS OF REHYDRATION BASED ON WEIGHT RESTORATION[1]

Potato Strips, 5/32 in. Thick, Not Soaked, Boiled 10 Minutes	Colorado Russet	Colorado Katahdin	Colorado Pawnee	Nebraska Triumph
Original raw material, Gm.	38.0	42.0	48.0	62.0
Water in raw product, per cent	75.5	77.5	80.6	85.0
Dry yield, Gm.[2]	10.0	10.0	10.0	10.0
Drying ratio	3.8	4.2	4.8	6.2
Rehydrated drained, Gm.	47.0	48.0	45.0	49.0
Rehydration ratio	4.7	4.8	4.5	4.9
Coefficient of rehydration	123.7	114.3	93.8	79.0

[1] From Davis and Howard (1943).
[2] Dry product containing approximately six per cent moisture.

in understanding this concept as shown in the following theoretical example. If it is assumed that there are two lots of potatoes, one containing 18 per cent total solids (A) and the other 22 per cent total solids (B), that 100 lbs. of each are dehydrated to six per cent moisture content and that peeling, trimming, cutting and blanching losses total 25 per cent in each case, one finds the relationship shown in Table 43.

Table 43 shows that raw material requirements are reduced by almost 20 per cent when using potatoes with 22 per cent solids as compared with raw material containing only 18 per cent solids. While there is seldom an opportunity in actual practice to make such comparisons as those assumed in the above example, the fact remains that solids content of the raw material is a highly important factor in the total cost of production.

Total solids can also play an important role in determining weight of rehydrated potatoes obtained from a given weight of dehydrated potatoes as pointed out by Davis and Howard (1943) as shown in Table 44. When high solids potatoes were dehydrated and then rehydrated, they absorbed more than their original amount of water. Low solids potatoes, on the other hand, absorbed less than the amount of moisture they originally contained, when they were rehydrated following dehydration. The authors carefully pointed out, however, that a great many factors can influence moisture absorption, and this must be kept in mind when these variations are considered.

Other Factors in Raw Material Selection

In addition to testing for reducing sugar content and total solids, raw material should be considered in terms of size, conformation to type, smoothness and freedom from secondary growth. Potatoes should be cut and examined internally for disease such as necrosis and other pathological damage in various forms, insect damage from beetle sting and wire worm and other obvious defects. A standardized cooking procedure such as steaming one-half to three-fourths inch slices under controlled time and temperature conditions with subsequent examination for color, flavor, odor and texture should be employed.

Information provided by the above tests and observations made of incoming raw material are extremely useful in determining changes in processing procedures that may be required in order to achieve optimum processing conditions for a given lot of raw material. Costly mistakes and unsuitable finished product can be largely eliminated by careful testing and selection of raw material for processing.

Over a number of years one variety has been found to have a consistently high percentage of the desirable factors outlined above. As a result of this, well over 90 per cent of the dehydrated diced potatoes currently being produced in this country are made from the Idaho Russet Burbank potato. Its consistently high performance characteristics have made possible the rapidly expanding potato processing industry in Idaho. Those interested in selection of other varieties would be well advised to use this variety as a yard stick for comparison. In addition to the other factors outlined it has good storage characteristics in fresh form.

PREPARATION FOR DRYING

Washing

Potatoes should be thoroughly washed to remove any adhering soil and to reduce the number of contaminating micro-organisms on the raw ma-

terial. In many instances potatoes are flumed from storage areas into the plant, water serving as a conveyor as well as a cleaning medium. There is a great deal to be said in favor of this technique in that it permits prolonged soaking which is helpful in removing stubbornly adhering soil. It is also useful in raising the temperature of potatoes—tempering—held at low storage temperatures. Fluming is also useful in the separation of potatoes from stones or rocks. Rotary drums or cylindrical washers are also often used very successfully in place of or in addition to washing in flumes. These units are usually 3 to 14 feet in diameter and 10 to 20 feet long and are constructed so as to permit the potatoes to scrub or abrade one another as the drum is rotated. Water sprays operating at pressures from 70 to 100 lbs. per sq. in. should be employed in sufficient volume to handle the desired flow of potatoes.

Preliminary inspection immediately after washing is desirable in order to remove potatoes that are unfit for processing due to "light greening," rot, mechanical injury or other serious defects. Extraneous material such as vines introduced by mechanical harvesting can also be removed at this point.

Peeling

Since this subject is covered in detail in other sections of the book, only a few brief statements pertinent to production of dehydrated potato dice are included. Years of experience have shown that the more time that elapses between harvesting and processing the more difficult the peeling, the greater the loss from peeling, and the greater the load on subsequent inspection facilities regardless of whether the diced dehydrated potatoes are inspected visually or by machine.

Steam and lye peeling are presently the principal peeling procedures used today in the manufacture of dehydrated potato dice. There are substantial arguments in favor of each of the methods. Under ideal circumstances a plant might find it advantageous to have both steam-and lye-peeling equipment. Consideration is being given to development of a combined system. It is generally felt that steam peeling is especially advantageous early in the processing season in that peeling losses may not be as great as with lye peeling. Later, as potatoes become more difficult to peel, lye peeling may be more economical. Careful consideration should be given to the low temperature lye-peeling techniques outlined by Olson and Treadway (1949) and Harrington *et al.* (1956). With either lye or steam it is possible to control the amount of skin and surface material to be removed and, under some circumstances, it may be cheaper to remove surface defects by increased peeling than to do so by trimming later in the process.

Careful attention should be given to prevention of discoloration whether steam or lye peeling is employed. Adequate cooling, washing and post-peeling treatments should be provided to minimize discoloration.

Minimum losses from peeling encountered in commercial operations amount to about ten per cent. Peeling losses above 15 per cent should certainly be carefully scrutinized. No set figure can be considered as ideal for a specific variety since variation in size and number of defects affect the amount of tissue which must be removed to achieve adequate peeling. Each lot of potatoes must be considered with respect to age, maturity, size distribution and other factors such as bruising and pathological defects in arriving at a reasonable estimation of the peeling loss which might be encountered with optimum peeling procedures.

Trimming and Inspection Prior to Cutting

This phase of processing is exceedingly important especially as it affects processing costs. Existing specifications used in the procurement of dehydrated dice permit 1 to 3 per cent by weight of defective units of any sort. To meet this requirement, a high level of workmanship is required. Until fairly recent years almost perfect trimming at this point was mandatory if this requirement was to be met. Under these conditions the amount of material that could be handled would vary from 150 to 1500 lbs. per woman hour depending on the age and condition of the potatoes. However, the use of electronic sorting machines is becoming fairly universal for the removal of blemishes or discolored units of the dried product. These units do not completely eliminate the need for visual inspection and trimming of the whole potato but do greatly reduce the amount of inspection required.

Careful attention to exposure time during trimming must be given to prevent excessive oxidation. During inspection and trimming, surfaces should be kept wet by water sprays located along the conveyors. Close supervision of labor is important as well as the type of equipment used if minimum trimming costs are to be obtained. Specially shaped trimming knives, spoons and shaving devices are available for removal of different types of blemishes.

Cutting or Dicing

Standard mechanical dicers which can be adjusted to cut the various sizes of pieces are used. Potatoes are fed to them usually accompanied by a small stream of water to keep the cutter blades lubricated and clean. Care must be exerted to keep the flow of potatoes within the rated capacity of the units otherwise excessive crowding will produce ragged and irregular cuts and excessive quantities of undersized pieces. The

TABLE 45

PREPARATION LOSSES[1] AS AFFECTED BY SIZE AND SHAPE OF POTATO PIECES[2]

Potato Piece Size, In.	Per cent Solids Lost Due to Cutting and Washing	Per cent Solids Lost Due to Steam Blanching
$3/8 \times 3/8 \times 5/8$	9.1	1.1
$3/8 \times 3/8 \times 3/8$	8.7	1.4
$3/8 \times 3/8 \times 3/16$	11.0	1.3
$3/8 \times 3/8 \times 1/8$	14.1	1.4
$1/2 \times 1/2 \times 1/8$	14.0	1.5

[1] Based on solids content of the trimmed potatoes.
[2] From Simon *et al.* (1953).

TABLE 46

MAJOR USES OF DICED DEHYDRATED POTATOES[1]

Size, In.	Canned Products	Other Products
$3/16 \times 3/16 \times 1/4$	Corned beef hash	...
$1/4 \times 1/4 \times 1/4$	Corned beef hash	...
$1/4 \times 1/4 \times 3/8$	Corned beef hash	Frozen meat pies
$3/8 \times 3/8 \times 3/16$	...	Army rations; hash browned
$3/8 \times 3/8 \times 3/8$	Soup	Potato salad; meat pies
$1/2 \times 1/2 \times 1/8$	...	Army rations
$3/4 \times 3/4 \times 1/8$	...	Potato salad
$3/4 \times 1 \times 3/8$	Beef stew	Potato salad

[1] From Willard (1957).

dicers should also be set up in such a manner that they can be easily serviced, and arranged so that a spare unit can be quickly moved into or out of position without interrupting operation of the line. Cutting knives must be kept sharp, clean and in good condition.

Since cutting actually splits cells and releases the intercellular contents, a cutting loss must be expected which is directly related to the amount of subdivision. Simon *et al.* (1953) reporting on the influence of piece size ran a careful study on losses due to cutting. A summary of their data is presented in Table 45. These measurements are in good agreement with those obtained by other workers and with a large number of industrial data and certainly point up the significance of losses encountered during cutting. The cut surfaces should be thoroughly washed prior to blanching. Small potatoes will yield less full-sized dice and the cutting losses are usually higher.

The many sizes and shapes into which potatoes are cut for dehydration have been discussed by Willard (1957), who presented information given in Table 46.

Blanching

Potatoes are composed of living tissue which contains a large number of enzymes—chemical catalysts that play an important role in the metabolic processes of all living matter. Some of these enzymes cause darkening of

the cut surface as discussed above, others are involved in carbohydrate transformations, and still others cause hydrolysis of fatty or lipid material in the potato. These must be destroyed or inactivated by heat or other means, otherwise potatoes will darken during dehydration and develop off-flavors and off-odors during storage. Blanching also serves to reduce microbiological contamination and affects the way the dehydrated product reconstitutes.

Blanching is conducted after cutting the potato tissue by heating, either in steam or water, at 200° to 212°F. While it is not known which enzymes are responsible for adverse quality changes in dehydrated potato dice, it has been found that sufficient heating to inactivate practically all of the peroxidase enzyme system is sufficient to impart the desired characteristics to the product.

Description of the test for determining whether potato tissue or dehydrated dice have been adequately blanched is given in a publication by the Western Regional Research Laboratory (Anon. 1944A). It is particularly useful because of its quantitative relationship to the degree of blanching. It requires relatively simple apparatus and is readily understood by operating personnel as well as those involved in control work. A new procedure by Morris (1958) may also prove to be useful for this purpose.

For those interested in further background on enzyme inactivation the following references are given: Anon. (1944A), Balls and Hale (1934), Cruess and Mrak (1940 and 1942), Cruess and Joslyn (1942), Cruess and Mackinney (1943), and Cruess *et al.* (1944A and B), Dixon (1934), Campbell *et al.* (1945), Proctor (1942), Davis (1942), Chace *et al.* (1941), and Lineweaver (1944).

Degree of blanching also has a very marked effect on the texture and appearance of the finished product as well as on the way the potato tissue dehydrates and reconstitutes. However, unless gross underblanching or overblanching conditions are involved, the rates of water imbibition are not too greatly affected. Excessive blanching leads to mushing or sloughing of the potato. Selection of the degree of blanch must therefore be conditioned by the end product performance desired. Reeve (1943) points out the effect of blanching on the swelling and gelation of the starch grains and follows the changes that occur through the dehydration process.

Blanching also has a very salutary effect in reducing the microbiological population that builds up during the previous processing steps. However, the extent of build-up of micro-organisms is a reflection of the sanitary conditions of the plant. Vaughn (1951), Vaughn *et al.* (1946) and Kueneman (1945) presented data showing the numbers of micro-organ-

isms present in samples of vegetable material taken from the lines of dehydration plants during World War II. It was shown that the total counts in these samples numbered into the millions prior to blanching but were reduced to insignificant levels at the discharge of the blancher. Vaughn very clearly pointed out the need for preventing recontamination in subsequent processing steps. Current military specifications do not set tolerances for microbiological counts.

Methods of Blanching

Potato dice are blanched by heating in steam or in water. In steam blanching they are heated by exposure to atmospheric steam either on stainless steel draper conveyor belts or, more recently, in a stainless steel screw conveyor which can be operated as a steam blancher. The latter may also be used as a combination steam and water blancher, or as a water blancher. Steam blanching is usually considered to result in less leaching of soluble solids than water blanching. Where water blanching is used leaching losses can be reduced by allowing soluble solids from the potatoes to accumulate in the blanching water until the desired concentration is obtained. This is called serial water blanching.

Blanching times may vary from two to twelve minutes depending upon the temperature used, size of piece, product load in the blancher, uniformity of heat distribution in the blancher, and variety and maturity of the potatoes being processed. The operator should be guided by end-product performance desired, temperature of the discharged product and enzyme tests in determining the proper blanching time. Superheated steam and high frequency electrical heating have been tried on a limited scale but have not been considered satisfactory from an operational or economic standpoint.

Immediately following blanching, a carefully applied rinsing spray is useful in removing surface gelatinized starch and preventing sticking during dehydration. Method of application and pressure should be controlled so as to minimize damage to the dice.

Sulfiting

All dehydrated diced potatoes purchased for the armed forces must be sulfited. Current Quartermaster specifications call for a minimum of 200 and a maximum of 500 p.p.m. sulfite content (as SO_2). Many of the products being distributed commercially also contain sulfite. In these cases labeling requirements of the Food and Drug Administration must be met. Some buyers' specifications do not call for sulfite because of certain difficulties encountered in remanufacture such as in the canned

meat industry where large quantities are used in corned beef hash and stews.

Sulfite is normally applied immediately after blanching as a spray of solutions of sodium sulfite, sodium bisulfite or sodium metabisulfite or combinations thereof. It may also be applied in the blanching water where water blanching is used. Sulfur dioxide has also been introduced into the product by means of combustion gases where direct fired tunnels or tubes are used in the dehydration step.

Sulfiting is a definite aid to production. It permits the use of higher temperatures during dehydration, thus increasing the rate of drying and the plant capacity. This not only reduces production costs but affects the rate of rehydration of the final product. It has been found that slow dehydration at low temperatures gives a hard dense product while use of higher temperatures results in a more porous material which rehydrates more rapidly.

Sulfite or sulfur dioxide protects the product from non-enzymatic browning or scorching during dehydration and increases the storage life of the product under adverse temperature conditions. Storage life is increased because the product begins storage in a better condition, and the rate of deterioration is substantially slower until the sulfite has been dissipated. However, sulfites should be regarded only as a useful tool rather than a crutch to support improper blanching or poor dehydration practices.

Mackinney (1945) reports that the beneficial effects of sulfites or sulfur dioxide can be nullified by high moisture content and that reduced moisture content enhances the effectiveness of sulfur dioxide, thus permitting the use of lower concentrations. He also reports that sulfur dioxide has an inhibiting effect rather than a masking effect in the prevention of heat damage. Sulfur dioxide content gradually diminishes during storage but its fate has not been fully determined.

Legault *et al.* (1951) found that sulfite increased by 1.9 to 5.1 times the length of time required to attain a given degree of browning. Ross (1948) reported similarly and found the protection decreased with increasing content of reducing sugars. Other references on effect of sulfite are Davis *et al.* (1942), Cruess *et al.* (1944A), Tomkins *et al.* (1944), Friar and Van Holten (1945), Caldwell *et al.* (1945), Green *et al.* (1946), Hearne and Tapsfield (1956), Legault *et al.* (1947 and 1951), Ross (1948), and Hendel *et al.* (1955A and 1955B).

Calcium Salts

Simon *et al.* (1953 and 1955) reviewed the effectiveness of calcium chloride in firming potatoes and prevention of sloughing as well as

its effectiveness in controlling heat damage. They reported on the feasibility of producing dice of a substantially different size, $^1/_2$ x $^1/_2$ x $^1/_8$ in., treated with calcium chloride and sulfite which was resistant to sloughing during cooking and which rehydrated rapidly. In preparing these, a solution containing calcium chloride and sodium bisulfite is sprayed on the dice as they emerge from the blancher. The solution should not contain sodium sulfite because precipitation of calcium sulfite will occur. Quartermaster specifications have been altered to permit this product after a joint study on the feasibility of producing it on a commercial scale was made by Kueneman and Wagner (1957). Subsequent purchases for the military have all been for this type of product. In view of its superior performance in a variety of recipes, this product is now being made available for commercial distribution and is expected to find wide acceptance in both the retail and institutional fields. Its field of usefulness extends from salads to casserole dishes. It can be used in any recipe calling for diced potatoes.

Additional references on the use of calcium salts in firming potatoes are Personius and Sharp (1939), Pyke and Johnson (1940), Whittenberger and Nutting (1950), and Campbell and Kilpatrick (1945).

DEHYDRATION

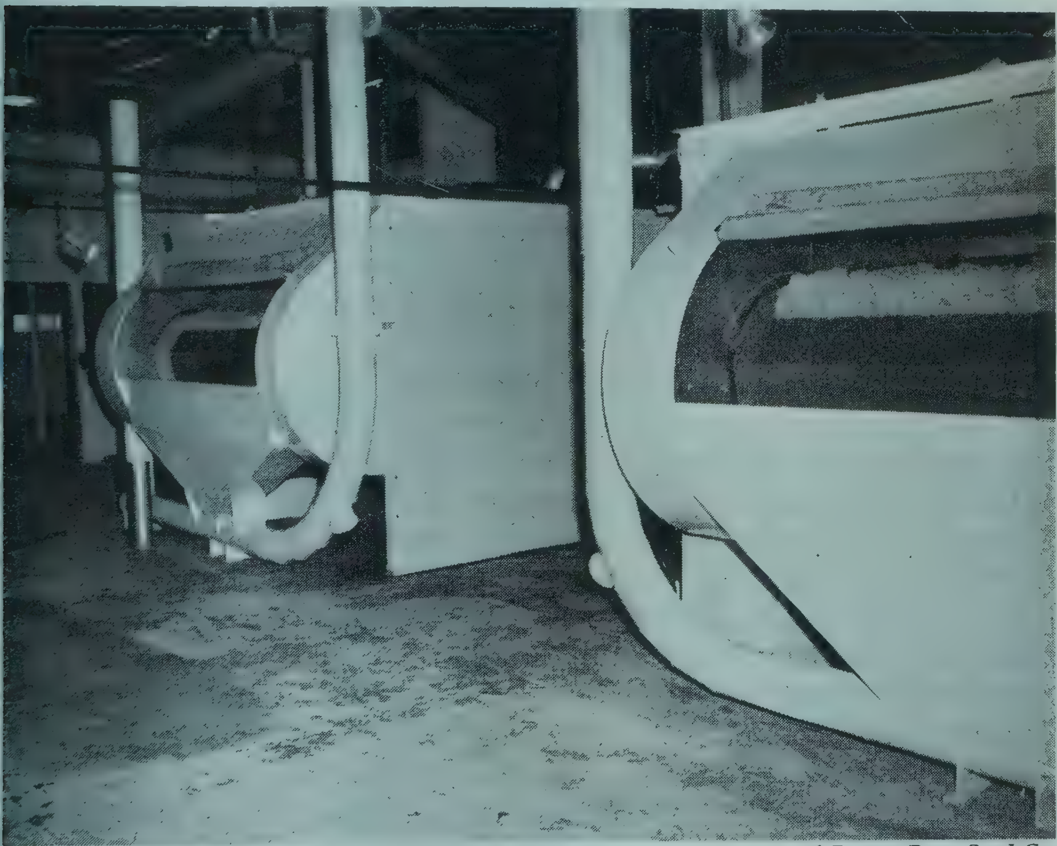
In view of the importance of dehydrated diced potatoes for military use probably more work has been done on this item since 1941 than any other dehydrated vegetable. Dehydrated diced potatoes have been successfully produced on practically every type of cabinet, tunnel and conveyor drier devised. Today, however, practically all the diced potatoes are produced on conveyor driers although a few tray and tunnel driers still exist. The advantages of the conveyor driers are numerous. Materials handling costs are tremendously reduced, loading and unloading are automatic. Indeed, the entire system lends itself well to complete instrumentation and automation. A modern conveyor drier is shown in Fig. 85.

The latest units incorporate features which permit the product to be carried through the final stages of drying previously handled by finishing bins so that a truly continuous system of drying is now possible. The conveyor drier is conveniently designed in stages so that the characteristics of the air with respect to temperature, humidity, quantity and air speed can be varied in such a way as to result in the highest quality of product.

Continuous belt or conveyor dehydrators have been in existence for years but have only been generally accepted in recent years. They are expensive to install but greatly reduce labor requirements. They have

great flexibility and permit precise control of temperature, volume of air and degree of recirculation. This permits the operator to select optimum conditions for dehydration. By proper combination of belt speed and depth of product a stage equivalent to "bin finishing" can be incorporated. Thus the discharged dried potato is ready for packaging after inspection by photoelectric sorting machines.

Conditions for dehydration in tunnels of various designs such as parallel flow, counter flow, and center exhaust have been described at great length by Chace *et al.* (1941), Cruess and Mackinney (1943), Anon.



Courtesy of Rogers Bros. Seed Co.

FIG. 85. A MODERN CONTINUOUS BELT DRIER USED IN DEHYDRATING POTATO DICE

(1944B), Tomkins *et al.* (1944), Kilpatrick *et al.* (1955), Wager *et al.* (1945), Anon. (1946), Hendel (1956), Ede and Hales (1948), and Van Arsdel (1947, 1951A, 1951B, and 1955) and others so completely that only the barest fundamental outlines need be covered here.

During the first stages of dehydration—the constant rate phase—moisture is readily removed and the drying rate is high. Higher dry bulb temperatures can be used at this stage than at any succeeding step. Recently, Lowe *et al.* (1955 and 1957) have described an entirely new type of drier

which they have called a "belt-trough drier." Though originally developed for the dehydrofreezing process, it may well lend itself to the dehydration of various potato products. With this type of drier efficient utilization of heat is achieved and very uniform drying is obtained.

The rate at which the product is carried through the constant rate phase of drying is exceedingly important since drying times for potato pieces in the low-moisture range are influenced by previous drying history. Potato pieces dried rapidly in the high-moisture range continue to dry rapidly in the low-moisture range.

Dehydration rate also affects the density of the final product. In general the faster the drying rate, the lower the density. Rehydration rates tend to follow dehydration rates.

Piece size has a tremendous effect on drying rate. The thicker the piece the slower the drying rate. This has been a limitation in expanding the use of dehydrated foods and especially in producing products for remanufacturing uses such as in stews, salads and other recipes that normally use a relatively large piece. An increase in thickness of piece size from $^1/_8$ in. to $^1/_2$ in. will reduce dehydrator capacity by about 90 per cent.

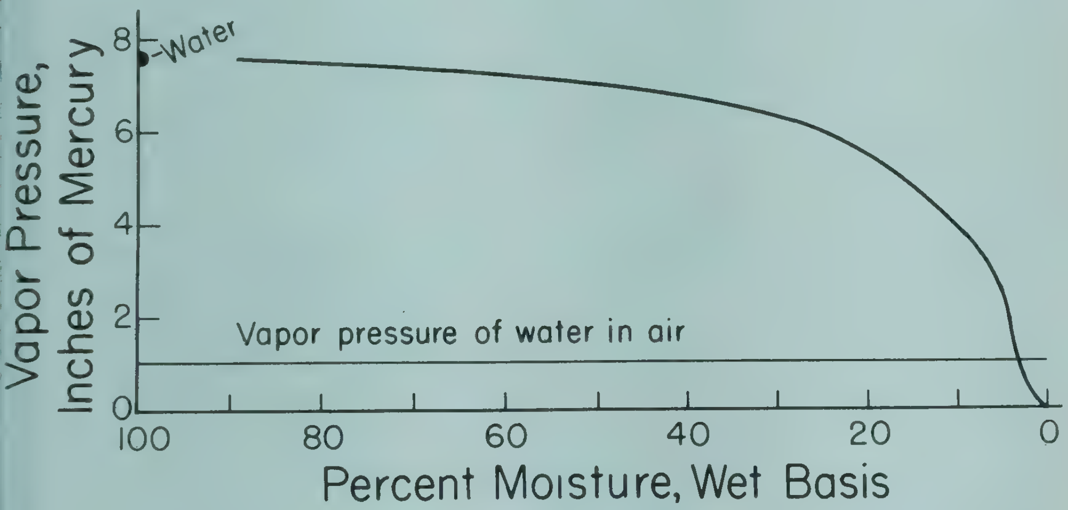
As drying is continued, the rate of moisture removal becomes slower and slower, the concentration of reactants within the potato tissue is increased, and the danger of damage to the product through non-enzymatic browning increases. Since storage life has been found to be very closely related to moisture content of the product, it is important to dry the product to as low a moisture content as is economically feasible.

The smaller sizes of dehydrated dice are dried fairly rapidly at progressively lower temperatures to 25 to 35 per cent moisture content on conveyor driers at temperatures ranging downward from 275° to 175°F. Time required for this initial drying step is about one hour. The following drop in moisture content to ten to fifteen per cent requires two to three times as long, at 140° to 160°F., and the final stages in the "falling-rate phase" may require 4 to 8 hours in finishing bin equipment, depending upon the final moisture content desired. Air temperatures used in bin drying are generally 100° to 140°F. Thus it can be seen that potato dice can be dehydrated in the flexible multi-stage conveyor system in a 6 to 8-hour cycle as compared to 10 to 14 hours required by the older conventional dehydrators.

It should be noted that dehydration is no longer an art but has become a science. This has come about by the large amount of fundamental research that has helped to clarify factors controlling the dehydration of fruits and vegetables. The more forward-looking firms have determined the fundamentals covering their particular products. As a result they

have been able to produce products of desired performance and of superior quality in the most efficient manner. This has been responsible for increased acceptance of dehydrated products.

Van Arsdel (1951A, 1951B and 1955) and others have attempted to give the drying process a mathematical treatment. They have done an excellent job of pointing out the relative importance of the factors involved in dehydration, and have stressed the fact that although the fundamentals of dehydration are the same for all vegetables, each vegetable has specific characteristics peculiar to itself which must be taken into consideration. Hendel *et al.* (1955A and 1956) have reported rates of heat damage that can be used in estimating rate of heat damage over a wide range of drying conditions.



From Van Arsdel (1951A)

FIG. 86. VAPOR PRESSURE OF A MOIST VEGETABLE AT 150°F.

It is generally agreed that the driving force in dehydration is the difference between the vapor pressure of the water in the product and the vapor pressure of the water in the air. Vapor pressure of the water in the air is easily determined by measuring the dry bulb and wet bulb temperature of the air to be used and then consulting a psychrometric chart. Vapor pressure of water in the product can be determined only experimentally, and is usually plotted as equilibrium humidity. In the case of diced potatoes these equilibrium humidity curves have been determined over a wide range of temperature and moistures (Hendel *et al.* 1955A and Hendel 1956).

In "constant rate" phase of dehydration, calculations based on vapor pressure difference are straightforward and simple. In the "falling rate"

From Van Arsdel (1951A)

FIG. 87. EXPERIMENTAL DRYING CURVE

phase a water diffusion factor enters the calculations. Diffusion rate in the latter phase is still tied to vapor pressure difference but piece size, shape and raw material characteristics must also be considered.

Data on dehydration rates obtained by Van Arsdel (1951A) are shown in Fig. 86. A straight line representing the vapor pressure of water in air (water content is 0.010 lb. water per lb. dry air) has been drawn. The figure shows that there is no great drop in the vapor pressure of the vegetable tissue until its moisture content has been reduced to 20 to 25 per cent. It should be pointed out that in drying a product from 80 per cent moisture content (20 per cent solids) to 25 per cent moisture content (75 per cent solids) one removes 92 per cent of total water; thus the bulk of dehydration is in the "constant rate" phase. This is shown graphically in Fig. 87, an experimental drying curve. By analyzing Figs. 86 and 87 one notes that vapor pressure difference correlates well with drying rate, even in the "falling rate" phase. A change in piece size will influence this "falling rate" curve, of course.

Tray and tunnel type dehydrators have been well described by investigators cited above. However, high labor costs and inability to control precisely drying conditions have caused this equipment to be abandoned by some of the dehydrators.

SCREENING AND INSPECTION

Following the final drying step, the diced material is usually screened to remove small pieces to bring the size distribution within specification limits. For example, existing military specifications Mil-P-1073A dated

Courtesy of Rogers Bros. Seed Co.

Fig. 88. Electronic Sorters Used in Removing Discolored Pieces from Dehydrated Potato Dice

December 12, 1950, require that not more than one per cent by weight of the product may pass through an eight-mesh U. S. standard screen (0.0937 inch openings). The bulk of these fines originate from the original dicing operation. Fines can also be created during removal of the dried product from the drier surfaces and through rough material handling. Aspiration and mechanical shaker screens are normally used for removal of fine material. Production of a high percentage of fines throughout the process

increases production costs since there is only a limited market for this material.

The dry product is then inspected either by manual sorting or the use of electronic sorters to remove discolored pieces. Each of these machines handles 30 to 40 lbs. of dry product per hour or the equivalent of 150 to 300 lbs. per hour of peeled potatoes. These units handle each piece individually, carrying it past the scanning beam of an electric eye. Blemished pieces are rejected ahead of the main flow discharge point. This equipment, which is available on a lease basis, has been very useful to the industry, but the labor savings on some lots of dehydrated potatoes have been much more clear cut than on others. Skilled operating and service personnel are required for successful use of this equipment. Fig. 88 shows electronic sorters used in this operation.

Production methods should be such that the product is reasonably within the limits of the electronic sorters or very close to specification limits if manual inspection is used. Due to the extremely large number of units per pound in some of the smaller cut sizes, it is virtually impossible to sort out economically many units in the dry stage. This of course relates to the efficiencies required in originally trimming the raw peeled potatoes.

It is also very desirable to install permanent type magnets in several places in the process line and especially immediately before the final inspection step prior to packaging. Small metallic pieces resembling iron filings crop up from conveyor chains and innumerable other places from the materials handling system and, of course, should be removed.

PACKAGING

There are relatively few problems involved in packaging dehydrated diced potatoes. Military procurement in recent years has been limited almost completely to the No. 10 can packed six to the case. Atmospheric packing is satisfactory. The No. 10 can has practically replaced the five-gallon square can used to such a great extent in World War II.

Dehydrated potato dice for remanufacture and other non-military uses are packed almost entirely in multi-wall kraft paper bags ranging in size from 5 to 60 lbs. A very limited amount for this market is packed in No. 10 cans.

QUALITY CONTROL AND SPECIFICATIONS FOR PROCUREMENT

Needs of the Quartermaster Corps have been a powerful stimulus in development of procedures for evaluating raw material suitability and product quality. The Appendix gives details, not readily available, of

procedures for determining specific gravity and reducing sugar content of the raw material (see p. 465).

A number of quality control procedures are outlined in Military Specification MIL-P-1073A and its amendments. These procedures have been used as a basis both for military procurement and for a large part of the commercial production since World War II. They have provided criteria for evaluating factors such as color, flavor, odor, texture, defective units, and fines. In addition a number of chemical procedures have been specified.

Peroxidase is determined by a modification of the guaiacol procedure of Western Regional Research Laboratory (Anon. 1944A). To increase the sensitivity, the analysis is carried out on dice that have been ground in a blendor. The original procedure specified use of whole dice, without grinding.

Moisture is determined by the six-hour vacuum oven method, on a fraction of material, ground in a blendor, that passes through a 20-mesh sieve and is retained on a 40-mesh sieve.

Sulfite may be determined by the rapid titration procedure of Potter and Hendel (1951). In case of question, however, the more accurate but time-consuming distillation method is used.

Quality control procedures such as these have been of great value to the dehydrated diced potato industry. By providing criteria for maintaining and improving quality, they have helped to make possible survival and growth of the industry since World War II, and to assure a prominent position for dehydrated diced potatoes in the markets of the future.

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R. H. Treadway

Potato Starch

About 15 per cent of the potato crop is normally made up of sub-standard potatoes unsuitable for the tablestock market because they are either too small, too large, misshapen, or damaged. Nearly all the cull and surplus potatoes, not fed to livestock, are used in starch manufacture.

Potato and wheat were the leading domestic starches early in the nineteenth century. According to Brautlecht (1940) the first potato starch plant in the United States was established in 1831 at Antrim, New Hampshire. The U. S. Tariff Commission (Anon. 1940) reported that by about 1880 there were more than 150 potato starch factories operating in Maine, New Hampshire, Vermont, Michigan, Wisconsin, Ohio and Minnesota. The industry, from its early history up to the present, has been largely made up of numerous small plants instead of several large factories, as we find in cornstarch manufacture. Many years ago in Maine and other States, special varieties of potatoes were grown for starch manufacture. These varieties were not of outstanding culinary quality but contained a relatively large amount of starch. In the Netherlands and Germany, different types of potatoes are still grown for tablestock and for industrial uses.

During the middle of the nineteenth century and somewhat beyond, the starch industry was one of the principal outlets for those potatoes grown in the northeastern part of the United States. According to Brautlecht (1953), 30 per cent of the 5 million bushels of potatoes grown in Maine in 1883 were used in starch production, 60 per cent for food, and the rest retained for seed.

Except for the early period, potatoes have never brought at the starch factory a price commensurate with the growing cost. Since the yield of starch is not much more than one-tenth the weight of the potatoes ground, factory operators cannot pay more than about 35 cents per 100 lbs. of potatoes and sell starch for 6 to 7 cents per lb. at the plant. In spite of the fact that potatoes to be used for starch production must be sold by the grower at a low price, starchmaking should be regarded as an integral part of a healthy potato industry. Diversion of cull and surplus potatoes

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to starch factories has done much to improve the quality of tablestock potatoes and establish more orderly marketing in the potato industry.

Late in the nineteenth century potato starch lost its strong position in the general field to cornstarch, which could be sold at a lower price. Potato starch then entered the category of specialty starches. Brautlecht (1940) reported that by 1900 the number of potato starch factories had decreased to 63. A decided trend developed toward concentrating the potato starch industry in Aroostook County, Maine, where 45 of the nation's plants were located. Northern Maine became a center for production of tablestock and seed potatoes, with the starch industry providing an outlet for the culls. In 1920 there were about 20 factories in Maine with a combined daily capacity of somewhat less than 75 tons of starch. Although the total productive capacity of Maine's starch industry has increased markedly since that time, owing to the construction of new plants and modernization of existing facilities, the number of plants has remained nearly the same.

The history of American potato starch thus consists of three phases:

1. The period from about 1850 to about 1900, in which it was a leading all-purpose starch.

2. The period from about 1900 to late in the 1930's when it was a specialty starch greatly overshadowed by corn and tapioca starches. During this interval much of the high quality potato starch used by American industry was of necessity imported.

3. The recent period in which an upsurge has occurred in the production of potato starch. Except for three of the years, large quantities of starch have been produced from each potato crop since 1950. A revival in the general usage of this starch has made it competitive with cornstarch, to a certain extent, in several applications. However, it should be kept in mind that over ten times as much cornstarch as potato starch is used.

Potato starch production is confined to the northern states where late-crop potatoes are stored throughout the winter. It would be difficult to operate a plant economically unless it has raw material available over a period of several months each year. The operating season or "campaign" is from about October to about June of the following year, to comprise around 200 operating days. Rarely, though, is the supply of cull potatoes sufficient and distributed so that plants can operate at capacity throughout the season.

PRODUCTION STATISTICS

At present there are 23 potato starch plants in Maine, with a total estimated capacity somewhat in excess of 250 tons of starch a day. A number of these plants have individual productive capacities of about 10

tons of starch per day, several as low as 5 tons, and a few as high as 25 tons per day. Maine's factories reached nearly 100 million lbs. total production level in the 1950–51 season. The 1951–52 season's production was low because of a short crop but other recent years have witnessed high production. According to Page (1957), the record high was set in 1956–57 with 114 million lbs. of starch produced in Maine.

Potato starch production was inaugurated in Idaho late in 1941 with the establishment of plants at Blackfoot and Twin Falls (Beresford and Aslett 1945). In 1942 a third plant was built at St. Anthony. The fourth plant for the State was established at Menan in 1944 but was later moved to Idaho Falls. Developments in 1948 included the construction of an additional plant at Idaho Falls, the rebuilding of the Twin Falls plant, and conversion of a glucose syrup plant at Jerome to starch manufacture. Plants were built recently at Idaho Falls and Aberdeen, bringing the total number in Idaho to eight. According to Carlsen (1957), Idaho starch plants have a total productive capacity of approximately 265 tons of finished product per day which is in the same magnitude as the combined capacity of Maine's 23 factories. Three of these plants are rated at 20, 25, and 30 tons per day, four at 35 tons, and the Twin Falls plant at 50 tons of starch daily. This latter plant has the highest capacity of any in the United States.

Two modern starch plants were built in the west in 1954–55—one at Moses Lake, Washington, having a 35-ton capacity and another at Monte Vista, Colorado, having a 25-ton capacity. The most recently established plants are those of about 25 tons capacity each, located at Riverhead, Long Island, New York and Grafton, North Dakota.

PRODUCTION METHODS

Although potatoes present more problems in storage and handling than does corn, they are definitely easier to process for starch recovery. In the wet processing of corn, the grain must be "steeped," i.e., soaked for about 48 hours, in warm water acidified with sulfur dioxide. Steeping is necessary primarily to soften the kernel so that the various constituents may be separated. Corn must be passed through a special mill to remove the germ of the kernel. The degerminated corn is then passed through buhr mills to disintegrate the tissue and permit separation of the fiber from the starch and gluten.

Potatoes, in contrast, are milled directly after leaving the washer. Either a rasp or a hammer mill is used to disintegrate the potato cells and liberate the starch. The skin and fiber are then separated from the starch by screening. Final purification is similar in both corn and potato starch

manufacture. Removal of the water solubles is effected by washing, and the remaining insoluble impurities are separated by any one of several types of equipment that utilize the difference in specific gravity between the starch and impurities.

A photomicrograph indicating the general nature of the tissue that must be disintegrated during milling is shown in Fig. 89. The cross section is from a low-starch potato sliced from the center of the tuber, where the starch content is quite low. In this particular section the

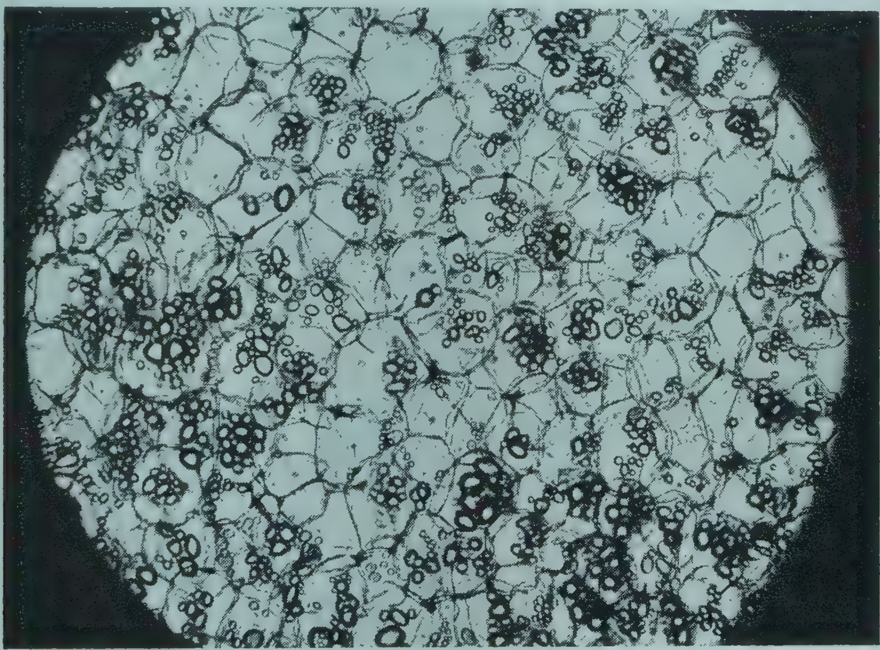

FIG. 89. SECTION 120μ THICK SLICED FROM THE PITHY AREA OF RAW POTATO TUBER SHOWING STARCH GRANULES

Magnification, 52×.

tissue contains only perhaps five per cent starch. However, for the purpose of illustrating how potato cells are grouped together and the manner in which starch granules are packed in the cells, it is preferable to examine a section containing relatively little starch. The walls of potato cells fit closely to one another with only occasional air spaces, in a pattern similar to a honeycomb cross section. The several more tightly packed cells shown in the illustration are typical of potatoes used in starch manufacture.

Maine

There is great variation in the processing details and in the equipment used to produce potato starch. Some of the oldest Maine plants use

simply-fashioned equipment with which the operators rasp the potatoes, screen off the fibrous material, settle the starch in vats, wash the starch by resuspending and resettling, dewater the starch and dry it. Many of the older plants have modernized to a greater or lesser degree. But even with the modernized plants and those built in recent years, there is wide latitude in selection of equipment and in arrangement of the individual steps comprising the processing.

What might be considered a typical Maine factory produces about ten tons of starch a day while consuming 80 to 90 tons of potatoes. The average composition of potatoes processed in Maine factories is estimated as given in Table 47.

TABLE 47

AVERAGE COMPOSITION OF POTATOES PROCESSED IN MAINE STARCH FACTORIES

Substance	Per cent
Starch	13
Protein (NX6.25)	2
Cellulosic material	1.5
Sugars	0.5
Mineral (ash)	1
Miscellaneous minor constituents (total)	1
Water	81

Potatoes received by the Idaho starch plants contain perhaps 15–16 per cent starch.

The process used in one Maine plant of 10-tons capacity is illustrated in Fig. 90. Although this plant is not of the latest type, it is efficient and turns out a high quality product. The process used is outlined in the following description. For a more complete discussion and operating data on potato starch processing, see Howerton and Treadway (1948).

Starch plants in Maine usually have storage facilities for handling at least 10,000–12,000 bushels of potatoes at the factory. The potatoes are removed from the storage bin by means of a flume which carries them to a conveyor and at the same time removes stones and much dirt. The conveyor lifts the potatoes up to the washer, where the remaining dirt is removed. The potatoes are then elevated to a hopper from which they fall to a screw conveyor that regulates the raw material flow to the rasp. The rasp reduces the potatoes to a slurry. The slurry is diluted with water to facilitate subsequent screening. Sulfur dioxide is added at this stage to inhibit the action of oxidative enzymes and thereby aid in producing a white starch. The dilute slurry is pumped to a battery of screens on which most of the cellulosic material is retained while the starch passes through.

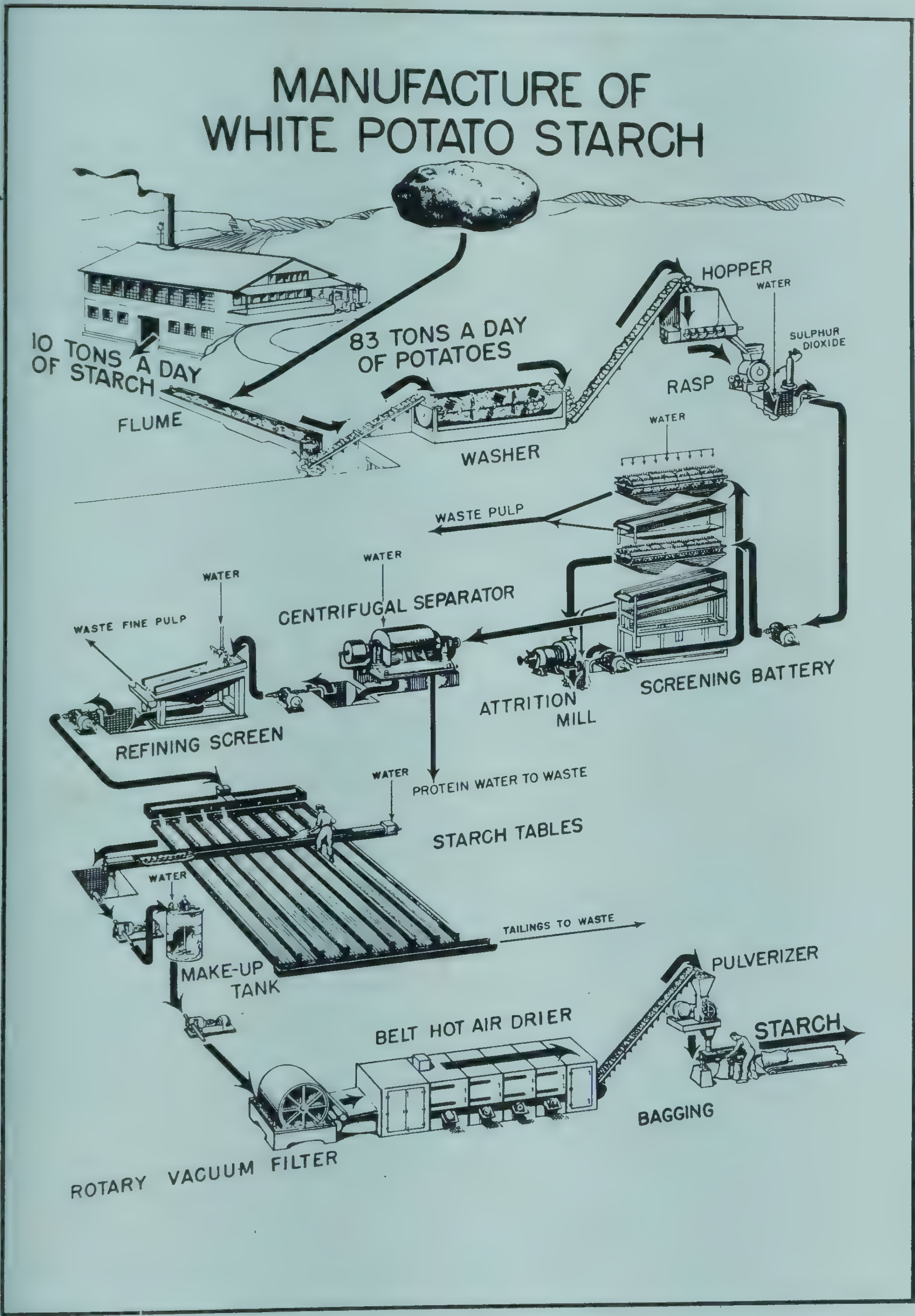

FIG. 90. FLOW DIAGRAM FOR MANUFACTURE OF POTATO STARCH USING SCREENING BATTERY AND TABLES

The screening battery consists of screens and sieves mounted vertically in the following order: Lower shaker screen (80-mesh), lower rotary brush sieve (perforated with 0.03 in.-diam. holes), upper shaker screen (100-mesh), and upper rotary brush sieve (perforated with 0.02 in.-diam. holes). In the screening operation the starch is first pumped onto the bottom sieve. Here the starch and water pass through and the pulp is discharged off the end of the sieve. The pulp is diluted with water and drops into an attrition mill for a second grinding to release a further quantity of starch. The starch suspension, with the fine pulp that passed through the lower sieve, falls onto the lower shaker screen. The starch granules pass through and most of the fine pulp is discharged from the end of the screen later to be mixed with the reground pulp from the attrition mill. The combined pulp is then pumped to the upper sieve where it is washed with a water spray. The fine pulp and starch pass through this sieve and drop onto the upper shaker screen. The starch suspension passes on through to the lower shaker screen. The fine pulp from the upper shaker screen and coarse pulp from the upper sieve are joined to constitute what is called the pomace or waste pulp which is discharged to the sewer.

The starch suspension from the screening battery is then pumped to a centrifugal separator where the "protein water," i.e., wash water containing the soluble materials, is removed. The starch from the continuous centrifuge is diluted with water and pumped to a refining screen (120-mesh) which removes additional fine pulp. The starch suspension is then pumped to tables where the starch settles and the remaining traces of fiber and soluble substances flow off at the end.

The starch cake is scraped from the tables and then diluted to the proper density for pumping to the continuous rotary vacuum filter. After dewatering to about 40 per cent moisture, the cake is dried in a continuous belt drier to about 17 per cent moisture (Muller 1941).

The finished starch has approximately the following percentage composition on the dry basis: starch, 98 to 98.5; ash, 0.3; cold-water-soluble compounds, 0.1. It contains about 0.5 per cent fibrous material and traces of nitrogen compounds and sugars.

Maine plant operators have made definite contributions toward improved technology in potato starch manufacture, extending throughout all phases. Thus, potato maceration was early accomplished by a homemade rasp constructed of a hollow, wooden drum covered with punched sheet metal. Steel rasps fitted with sawtooth blades on the surface parallel to the axis of the drum were later introduced. Hammer mills were also employed for the grinding of the potatoes and attrition mills

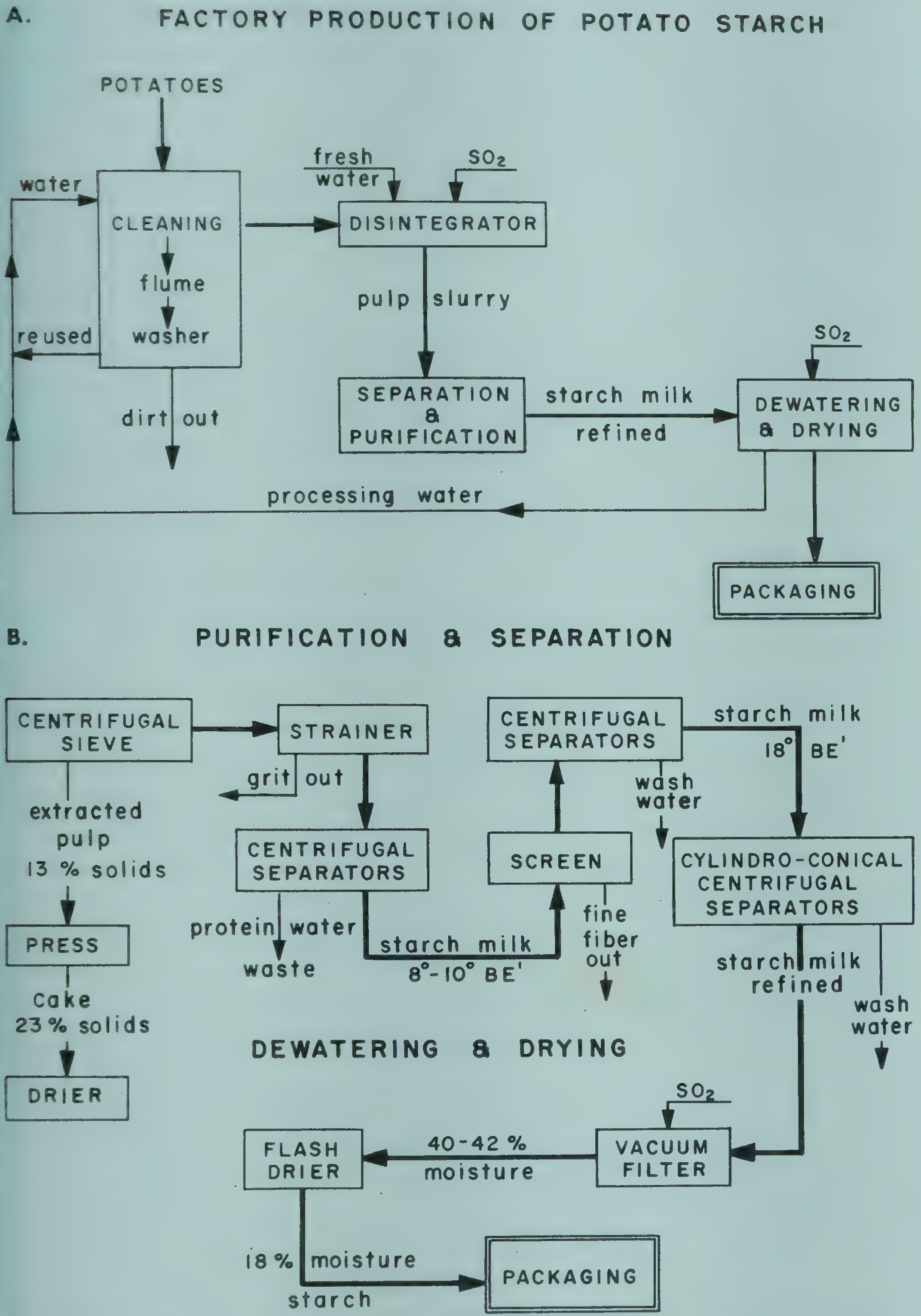

Fig. 91. (A) Principal Steps in Potato Starch Processing. (B) Modern Potato Starch Processing

Detail showing extraction of waste pulp by centrifugal rotating sieves, purification of starch milk, dewatering and drying of starch.

for grinding the once-extracted pulp. The oldest Maine plants washed the starch in wooden vats. This practice gave way to use of concrete vats. Tables were later used to settle the starch from the processing water. Dewatering of starch was later improved by use of centrifuges or vacuum filters. Maine processors have made much progress in starch drying methods, proceeding from open-air drying on racks in stove-heated drying houses to the adoption of rotary "turbo" (ring story), and of continuous-belt driers.

Idaho

Idaho processors have also made their share of contributions toward advances in potato starch production methods. They were first to grind potatoes using a type of disintegrator that combines features of a centrifuge with a vertical hammer mill. In this disintegrator, a vertical rotor with hammers in horizontal plane rotates at high speed within a 360°-screen enclosure. The potato macerate is swirled against the perforated cylinder, and the finely-comminuted pulp is forced through the holes. Most of the Idaho plants use similar equipment and procedures. Following disintegration of the potatoes, the pulp is screened to separate the free starch and then reground to liberate more starch. Screens ranging from 80- to 120-mesh are used to separate the coarse fiber and 120- to 150-mesh screens for removing much of the fine fiber. Horizontal, continuous centrifugals are used to remove the protein water. Settling vats are usually employed for removing the small quantity of remaining fine fiber and insoluble impurities that settle at the top in the so-called "brown starch" layer. The purified starch is dewatered by rotary vacuum filters.

Idaho plant operators pioneered in the use of cyclone "flash" driers. Although there is some variation in the number of stages and in the air temperature used, conditions employed in one of the leading plants will be used as an illustration. Pre-drying of the moist starch from the vacuum filter is effected in a screw conveyor through which 290°F. air passes countercurrently. The partially-dried starch then drops into a high speed blower where it is mixed with 290°F. air. The moisture laden air and starch are separated in a cyclone dust collector. This is repeated by passing the starch through three additional blowers and cyclone separators. A fifth blower-cyclone cools the starch before bagging. The following advantages are claimed for flash drying: (1) less capital investment relative to other driers; (2) less fuel requirement; and (3) more flexible control of moisture content of finished product in this rapid type of drying.

Typical Plant of Most Recent Construction

Fig. 91 in its sections (a) and (b) presents a flow chart of the operations in one of the most modern and most recently constructed potato starch plants. Section (a) depicts all the principal operations in brief form, and section (b) charts details in the purification, separation, and final operations. The disintegrator used is of the vertical hammer mill type, the action of which was described under the preceding discussion of Idaho plants. The centrifugal rotating sieves, first used in Europe, have been installed in several of the newest United States factories. In construction, they bear some resemblance to a centrifugal pump, but with slotted sieve plates in place of the impeller vanes. The pulp slurry enters the rotating sieve through a central feed pipe and then flows radially outward along sieve plates. Centrifugal force drives the starch milk through the slots in the sieve plates, from which it is discharged through an outlet. The coarse pulp, which cannot pass through the slots, is discharged through a separate outlet. Several centrifugal sieves are usually employed in series. An advantage over ordinary screen separation is that the percentage solids content of the waste pulp from the centrifugal sieve is about three times that of pulp from the conventional screen. In operations of the factory whose flow chart is given, the extracted pulp having 13 per cent solids content is pressed to 23 per cent solids and then dried to provide a component for livestock feed.

On examining the series of processing steps used in a modern potato starch factory, the average person is amazed at the multiple washings and screenings employed to obtain a final product as pure as possible but still one that sells at a relatively low price. The final purification of starch milk is carried out by passage through a battery of cylindroconical centrifugals. These compact vertical units provide efficient removal of soluble impurities and separation of the starch from the wash water by centrifugal force. Dewatering and drying are conducted by the same methods described in the discussion of Idaho plants.

STARCH FRACTIONS, MODIFICATIONS AND DERIVATIVES

Potato starch fractions have recently become available in the United States as a result of sizable production in the Netherlands. Following extensive research in this country and elsewhere, Dutch chemical engineers developed a successful process and built a plant that can produce in one day 17 tons of the branched fraction amylopectin and 6 tons of the cellulose-like, straight chain fraction amylose (Anon. 1958). In the fractionation process the starch is first autoclaved at 310°F. in 13 per cent magnesium sulfate solution; the amylose is separated by cooling

the mixture below 200°, and most of the amylopectin is then removed from the supernatant liquid by cooling to room temperature and salting it out with additional magnesium sulfate. Potato starch, like other principal commercial starches, contains 74 to 78 per cent amylopectin.

Uses for amylose are still largely in the experimental stage but it can be made into transparent, edible films with potential use for food packaging and casings. It has definite possibilities in paper sizing and coating and in textile sizing. It can also be used to prepare chemical derivatives having properties similar to commercially successful cellulose derivatives. Amylopectin is used in the sizing and coating of paper, in textile sizing, as a thickener in foods, and has several potential uses. At the time of its introduction, amylose was priced at 25 cents and amylopectin at 16 cents per lb. in carload quantities (Anon. 1957A).

Most of the potato starch is sold in the native, unmodified form. For many years, however, sizable tonnages have been converted annually into dextrins by roasting and into pregelatinized starch. A few plants convert part of their production into thin-boiling starches by acid treatments and to oxidized starch, usually by sodium hypochlorite treatment. Thin-boiling starches are useful when it is desired to have higher solids content paste without raising the consistency unduly. Oxidized starch pastes are noted for their increased clarity and diminished tendency to thicken on cooling. However, oxidation under special conditions can be made to yield a product giving pastes of higher consistency than that of unmodified starch.

Several American potato starch processors have converted the starch by acid hydrolysis to glucose syrup and dextrose sugar, but this has been done only in emergency situations, such as during World War II when sugars and corn were under allocation.

Oxidation of starch by periodic acid produces a specific type of oxidation to give "dialdehyde starch" or "oxystarch." Oxystarch can be made economically by electrolytic regeneration of periodate; by regulating the extent of treatment, products can be formed that represent a wide range of aldehyde content. Oxystarch is presently under investigation in the tanning of hides and for other potential uses.

Much research has been conducted on the production of starch esters, such as starch acetate, and on ethers, such as allyl starch and hydroxyethyl starch. Production of these chemical derivatives was at such a level in 1958 to require about 50 million lbs. of cornstarch, but little potato starch is believed to be used in derivative manufacture in the United States. Hydroxyethyl starch gums produced by reaction of ethylene oxide with potato starch are made in rather large tonnage in the Netherlands. Some derivatives, in which only a minor part of the

hydroxyl groups of the starch molecule are substituted, are available which disperse in water to give pastes of unusually high consistency.

UTILIZATION OF POTATO STARCH

Maine potato starch is used in its various outlets in approximately the following proportions, expressed in percentages (Anon. 1957B): paper, 60; textiles, 30; food, adhesives, and miscellaneous, 10.

During the period prior to World War II domestic potato starch nearly always sold at a higher price than cornstarch. Imported potato starch at times sold at about twice the price of domestic cornstarch (Anon. 1940). For many years this price relationship confined the use of potato starch to special applications in which its unique properties make it preferable. The availability of imported tapioca starch at a price generally competitive with cornstarch was another factor limiting the demand for potato starch during the decade preceding World War II. Tapioca imports reached the high level of 433 million lbs. in 1937, which can be compared with 685 million lbs. of cornstarch sold that year in the United States for use as starch (Anon. 1940). The total cornstarch production in 1937, however, was about 2.4 billion lbs., including 1.5 billion lbs. used for glucose syrup and sugar manufacture. The remaining 0.9 billion lbs. was used for export and manufacture of dextrins and modified starches. The demand for domestic potato starch in 1937, however, was sufficient to result in the sale of only 17 million lbs. of starch.

Most of the tapioca starch used in the United States during the 1930's was imported from the Netherlands Indies. In fact, a high percentage of the total tapioca starch exported from that country at the time was shipped to the United States. Outbreak of the war in the Pacific late in 1941 cut off imports from this source. Fortunately our domestic white potato starch industry began expanding and modernizing in 1938 and was thus able to meet increased demand for its product. As a result potato starch production was increased to furnish a sufficient supply of this starch for the most essential uses and to replace in part the unavailable imported root and tuber starches.

Following the close of World War II, importation of tapioca starch was slowly resumed. By 1955, tapioca imports principally from Brazil, Thailand, and Indonesia had reached an estimated 50 million lbs. per year.

In recent years potato starch and cornstarch have sold in the same price range, with potato starch bringing six to six and one-half cents per pound at the plant. The price of potato starch has been rather stable, without much disturbance as a result of moderate imports of potato starch from the Netherlands and other European countries and of the incoming tapioca starch.

Paper

Although it has long been known that potato starch has valuable properties for many applications in paper manufacture, its use previously was not common, even in mills in starch producing areas. During the past several years, however, expanded use in the paper industry has been the leading potato starch development.

Starch is used for four purposes in paper manufacture: (a) beater sizing in which the cellulosic fibers are cemented together preparatory to sheet formation; (b) tub sizing, in which the preformed sheet is passed through a dilute size solution; (c) calender sizing, in which a smooth finish is imparted; and (d) surface coating, which is an optional step in finishing high-grade papers. Starches and dextrins are also used in combining and sealing paperboard in the fabrication of folding, corrugated, and laminated solid-fiber boxes.

Cold-water-soluble potato starch is outstanding in the performance in beater sizing. This modification is produced by cooking a suspension of the starch, drying the paste on drum driers, and grinding the flakes to a powder. This type of soluble potato starch was first manufactured in The Netherlands and has been produced for years in this country to supply a steady market. Soluble potato starch or "gum" is preferred to the corresponding products from other starches in beater sizing because its paste possesses great stringiness and cohesive strength. Furthermore, these properties are said to be affected relatively little on addition of alum. Alum is regularly used in paper manufacture, and its acidic character is detrimental to the properties of most starch pastes.

Potato starch is well liked relative to cereal starches in coating smooth, white paper such as that used in magazines. The unusually strong binding power of potato starch for the white pigments and clay is advantageous here. Potato starch is said to have replaced much casein formerly used in paper coating.

Textiles

Most of the potato starch used in the textile industry is employed in the sizing of cotton, worsted, and spun rayon warps. In warp sizing, parallel threads that run lengthwise in the loom dip into a bath of hot starch paste formulation; the sized thread passes over heated drums to effect drying after leaving the bath. The function of warp sizing is to bind tightly the loose fibers to the surface of the thread and thereby strengthen and protect the warp from abrasion during weaving. "High count" warps, containing many individual fibers spun together, are difficult to size because of small interstitial space between the fibers. Potato starch is preferred to cereal starches in warp sizing because its paste penetrates farther be-

fore gelling. Deeper penetration of the starch results in formation of a film that adheres well to the warp and consequently gives it more strength and resistance to abrasion. It is well known that potato starch films have a high degree of toughness and flexibility relative to other starches. This permits potato starch-sized warps to be woven at lower humidity than those sized with cornstarch.

The smooth clear pastes obtained with potato starch also have other advantages in warp sizing. Cereal starch pastes frequently contain large aggregates of gelled material which stick to the warp and subsequently get caught in the loom to cause thread breakage. Warps sized with potato starch not only have a smoother finish but also are easier to desize after the size has served its purpose. The lesser tendency of potato starch pastes, in comparison to cereal starch pastes, to "set back" or retrograde to a gel is of advantage following shutdowns. It is also claimed that less tallow is required in potato starch sizes to minimize sticking of warp to drying drums than with other common starches. Potato starch is said to be superior for sizing warps that have been previously dyed in that it gives a brighter color.

The finishing of cotton sewing thread is similar to warp sizing. The thread is immersed in a finishing bath and then passed over brushes to provide a smooth finish. Many manufacturers of cotton thread, like textile manufacturers in their warp sizing, use potato starch exclusively.

Potato starch is not outstanding in its ability to bring out color intensity of vat dyes when used as a thickener for textile printing pastes, but it possesses superior properties as a finishing agent. Cloth finished with potato starch has a better "feel" and smoother surface than is obtained with cereal starches.

Food

Much of the potato starch utilized in the food industry is used in bakers' specialty items, such as Swedish and German style breads, in crackers and in matzoth. It is also used as a thickener in soups and gravies. Potato starch has been pelleted successfully to make puddings similar to those ordinarily made from tapioca starch. Pregelatinized potato starch is used in considerable quantity in "instant" puddings, in which its properties are preferable to those of cereal starches. The dry formulation of instant puddings is principally soluble starch, sugar and flavoring. Upon addition of cold milk, the starch quickly dissolves and then sets to a gelled pudding.

Starch is used in the confectionery industry for the following purposes: (a) as a medium for molding cast candies such as jelly beans, "orange

slices" and gum drops; (b) as a bodying agent and to impart smoothness and stability to caramels and marshmallow; (c) as a thickening agent in synthetic jellies; (d) as a dusting agent, perhaps mixed with powdered sugar, for candy gums, chewing gum, etc. Thin-boiling starch rather than thick-boiling starch (unmodified) is ordinarily used as an ingredient in candy manufacture. Starch constitues 10 to 12 per cent of the total weight of dry ingredients in candy gums. Glucose syrup, produced by the hydrolysis of starch, is widely used in candies, beverages, chewing gum, ice cream and confections in general.

Adhesives

In producing adhesives it is generally advantageous to modify starch by chemical or physical treatment to reduce its paste viscosity, thereby permitting use of higher solids concentration, and to develop so-called tackiness. Although some potato starch used in adhesives is of the so-called thin-boiling and oxidized modifications, most of it is used in the dextrinized form for this purpose. Dextrins are produced by roasting starch in the presence of an acid catalyst. It is a well known fact that films of dextrin made from root and tuber starches, such as tapioca, sweet potato and potato, have greater flexibility and resistance to checking than dextrins of cereal starches. Potato dextrins are used in many applications in which their specific properties make them desirable; for example, as a binder in sand paper, abrasive cloth, bookbinding and rug sizing, each of which requires a dextrin of high paste tackiness and of flexible residual film. Potato dextrin films are also outstanding for their ease in remoistening; this property is desired in mucilages used for gumming stamps, labels, envelopes, paper tape, etc.

Miscellaneous Uses

There are a number of miscellaneous uses of starch that cannot be classified under the general categories discussed above. Examples of these uses include utilization of starch as (a) hygroscopic additive in baking powder; (b) fermentation raw material; (c) binder for tablets; (d) binder and extender for sausages; (e) builder for soap; (f) separator in dry cell batteries; (g) raw material for nitro-starch manufacture; (h) consistency stabilizer for oil well drilling "muds," (i) attractant in insecticidal mixtures; (j) boiler feed water treating agent; and (k) clarifying agent for waters used in mining operations. The miscellaneous uses of potato starch undoubtedly include some of these listed. Manufacturers and distributors of potato starch, for business reasons, hold as confidential information concerning some of the lesser uses of their product.

OUTLOOK FOR POTATO STARCH

The potato starch industry has made great strides during the past 15–20 years in providing its consumers with a larger and more dependable supply of higher quality domestic starch than heretofore available. The demand constantly exists for large quantities of potato starch. It is impossible to predict exactly how fluctuations in the size of future potato crops may affect starch production. However, many leaders in the potato industry believe that closer grading of tablestock potatoes in the future will assure an adequate supply of culls for starch manufacture even in years of only moderate volume of potato production. Continued growth of the potato starch industry depends primarily upon whether the manufacturers can continue to match the competition of other starches in quality, supply and price.

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Miles J. Willard

Potato Flour

Potato flour is the oldest commercial form of processed potato. It is widely used by the baking industry, both in this country and abroad, although its growth has not kept pace with the other segments of the potato processing industry. Potato flour is produced in this country by two firms, one operating in Minnesota, and the second having plants in Idaho and North Dakota.

Potato flour has long been associated with the baking of bread. It is accepted that small amounts of added potato solids help to retain the freshness of bread. They also impart a distinctive, pleasing flavor and improved toasting qualities. Other uses in the baking industry, which is the largest single user of potato flour, are described later in this chapter.

The manufacture of potato flour is basically a simple dehydration process. There have been no major changes in the method of manufacture since the drum drier equipped with auxiliary rolls was developed in Germany in the last century. Consequently, this chapter may be considered a general discussion of a well-known process.

It would be wrong to give the impression that potato flour is such a standardized product that there is little expectation for improvement in quality or for increase in its use. The rapid strides in potato technology made in the last decade are pointing the way for improvements in this product considered impossible in the past.

HISTORICAL BACKGROUND

Dried potatoes were originally developed commercially as an animal food. In the year 1901, a German patent was issued for the drying of cooked, whole, unpeeled potatoes on the surface of a drum drier. The potatoes were spread on the surface of this drier by an auxiliary roll rotating in contact with the drying drum. The crude dried potato solids were roughly ground and used as stock feed.

The name "potato flour" is also given to the product obtained by grinding dried, sliced potatoes. Stock feed has been made by this procedure in the United States and in Europe, generally by direct contact of the sliced potatoes with hot furnace gases. The dehydrated pieces were subsequently ground to a fine flour (Rendle 1945).

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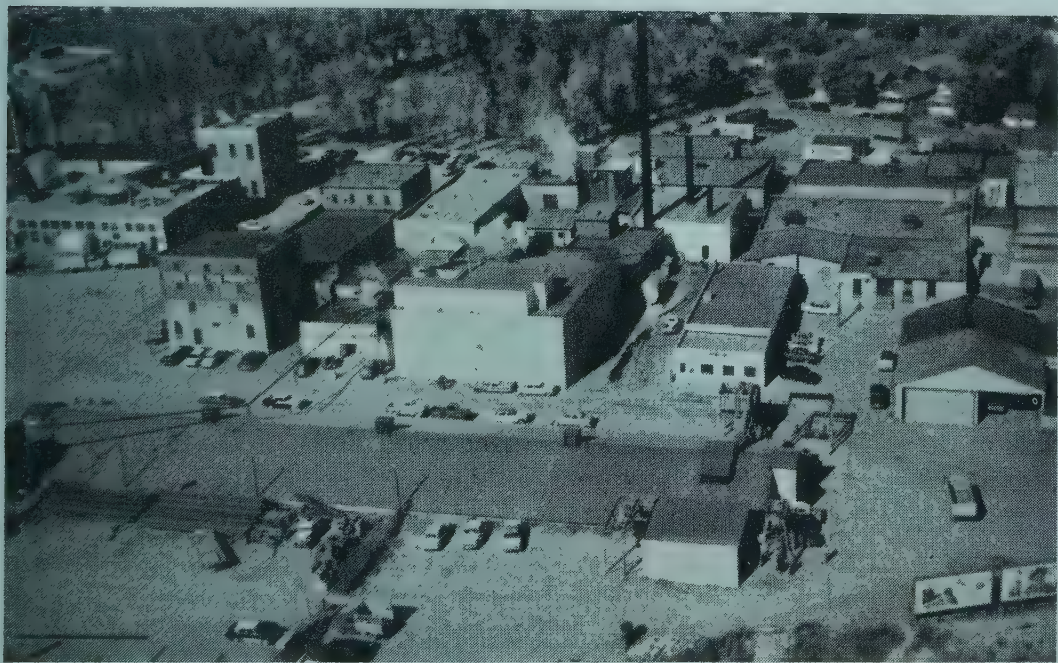
About 1917, the drum drying process was brought to this country from Germany and established at Cadillac, Michigan, and Idaho Falls, Idaho. By this time, the process had been improved to the point where the flour was being produced for human consumption in the Netherlands, Denmark, and Germany. The production of flour by this method expanded during the First World War when it was offered to the public as a substitute for wheat flour. Due to food shortages, and prompted by patriotic motives, a large number of people were enthusiastic about using it, but when the necessity for substitutes no longer existed, the demand for potato flour lessened (Noel 1922).



Courtesy of Rogers Bros. Seed Co.

FIG. 92. AERIAL VIEW OF A POTATO PROCESSING PLANT IN IDAHO FALLS, IDAHO

Operations were started here about 1917 making this one of the earliest multi-product potato processing plants established in this country.

The site of the original flour installation in this country, at Idaho Falls, Idaho, is thought to be the birthplace of the potato processing industry (exclusive of starch) in this country. Potato flour has been produced here continuously since 1926, in addition to other forms of dehydrated potatoes. An aerial view of a plant producing a variety of dehydrated potato products including potato flour is shown in Fig. 92.

The industry gradually expanded after World War I. American manufacturers began fabricating single drum driers with applicator rolls or so-called "flaking" machines. The original German driers were actually

"twin" drum driers. Two drums placed close together were fed from one central point. Fig. 93 shows this arrangement in comparison with the more satisfactory single drum unit developed in this country.

It soon became apparent that the margin of profit in potato flour manufacture under normal conditions was not large and that to be profitable, a large volume of production was necessary. A minimum capacity of four tons of flour per day was considered necessary, although most plants were capable of making 3 to 4 times this amount in a 24-hour period.

One of the early problems associated with potato flour was overcome during this period by improved processing methods. Potato flour manufactured in Europe commonly had a high spore count. These bacterial spores (*B. mesentericus*) multiplied rapidly during the fermentation and proofing of bread doughs, and the finished loaf of "ropy" bread developed a bad odor and a sticky, stringy crumb. This problem was gradually overcome as washing and peeling facilities were improved and as plant sanitation became more effective. The cause of rope was also attributed to ingredients in bread other than the flour (Hoffman *et al.* 1937).

A phenomenal but short lived expansion of the potato flour industry occurred during the years 1948-49. Due to the large surplus of potatoes in these years and the urgent need for food in Europe, the Commodity Credit Corporation of the U. S. Department of Agriculture instituted a program to procure 460 million lbs. of potato flour for export. This flour was to be shipped to Europe and the Occupied Zone of Germany, where much of it was flown in by the famous "Air Lift" operation.

Between July 1948 and the middle of 1949, 348 million lbs. of potato flour were exported to Germany. The nation's capacity for producing potato flour had previously been about 30 million lbs. a year, although the actual production was somewhat less than this figure.

Both cooked and uncooked types of flour were supplied during this period. Much of the cooked potato flour was made by the process to be described later in this chapter on the traditional "flakers." Standard double drum driers, ordinarily used for drying distillers' solubles, were also used. Many of these driers were idle in distilleries at this time. A process for the utilization of this equipment was developed by the Department of Agriculture (Edwards and Hoersch 1948).

Uncooked potato flour made during this period varied considerably in quality and method of manufacture. Many dehydration plants that ordinarily processed apples, onions or carrots, simply dried the sliced raw potatoes on trays or in kilns. Several methods of drying raw, ground potatoes were developed by engineers of the Department of Agriculture (Edwards and Hoersch 1948; Eskew and Edwards 1950). One of the simplest ways developed was to grind the washed potatoes in a hammer

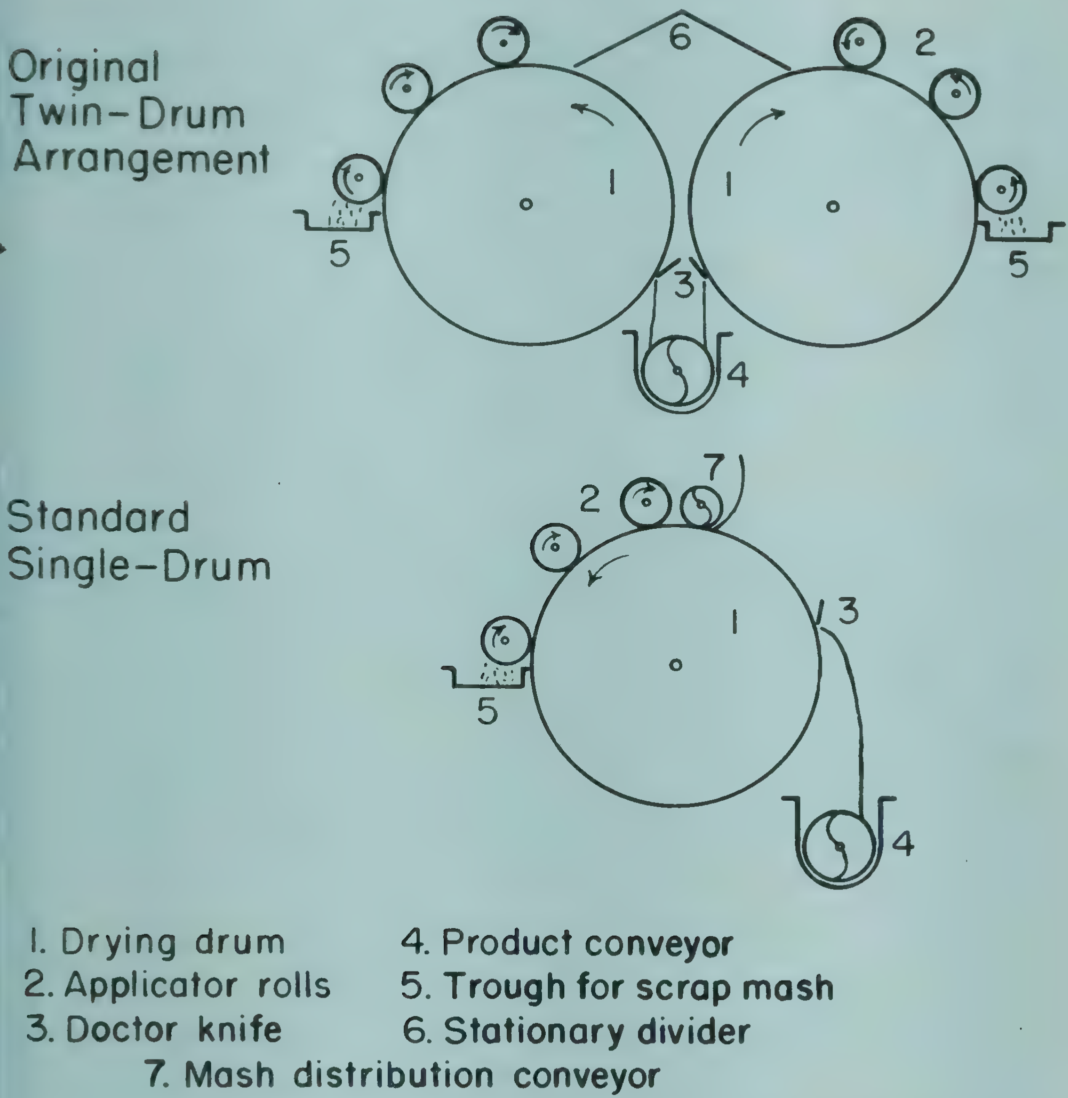


FIG. 93. SCHEMATIC DRAWING OF DOUBLE-DRUM AND SINGLE-DRUM DRIERS USED IN DEHYDRATING VARIOUS FOOD AND NON-FOOD PRODUCTS

mill and dry them in a steam-tube drier. An equal weight of previously dried product was added back to the raw, ground material in order to avoid lumping and baking on the heated tubes. The granular product was then ground to flour.

Sulfur dioxide (0.1 per cent) was added to the ground potatoes immediately after coming from the hammer mill in order to retain a light colored product. This process was also applied to high-temperature rotary driers, using gas, oil or coal as a source of heat (Edwards and Hoersch 1952).

Much of the flour made during this period of emergency was inferior to that normally produced by the potato flour industry in this country. Elimination of the cooking step greatly facilitated drying rates, but did not

inactivate the enzymes in the flour. The high sulfite levels used to prevent discoloration of uncooked potato flour would not be accepted by our baking industry today. However, the rapid mobilization of the industry to meet the need was outstanding. Following this short period of large scale production only those manufacturers with facilities geared to the baking industry remained in the business.

METHODS OF MANUFACTURE

Over a period of many years there has been a gradual improvement in the quality of potato flour. One of the most important factors contributing to this improvement has been the up-grading of potatoes used in preparing this product.

Raw material for potato flour consists primarily of "culls" that remain after the U. S. No. 1's and 2's are removed for fresh market or other uses. Under the diversion program being maintained by the U. S. Department of Agriculture, some graded potatoes also are utilized in the production of potato flour.

A fairly large percentage of potatoes do not qualify as U. S. No. 1's or 2's because of defects, such as irregular shape, large or small size, and excessive skinning, which do not affect their suitability for food use. Along with these potatoes are others that are sunburned, rotted, scabby or blighted, and other diseased or mechanically damaged stock. The price commanded by graded potatoes fluctuates widely and is quickly affected by market conditions and supply. On the other hand, the price of cull potatoes is quite stable and is not greatly affected by market conditions.

The quality of cull potatoes varies widely in the various growing areas of this country. Where little emphasis is given to the quality or grade of market-bound potatoes, the cull stock may be of very poor quality, fit only for animal feed. But in a number of areas, strict grower-shipper marketing agreements are in force. In these areas the quality of graded potatoes is maintained at a high standard and the higher quality of the culls or sort-out reflects the strict regulations. Only in areas such as these, where large quantities of high-grade culls are available consistently, at a relatively stable low price, can a potato flour operation be economically conducted. The potato starch industry utilizes many cull potatoes and competes with the potato flour manufacturer for raw material for processing at a very low price. In competing for raw material, it would appear that the flour manufacturer has an advantage since a higher yield of product from the raw material is obtained in flour manufacture. One hundred pounds of sound Idaho potatoes will yield about $12^1/_2$ lbs. of potato starch. If converted to potato flour the yield would be about $14^1/_2$ lbs, as the flour contains the entire solid content of the potato.

However, to make potato flour of high quality that is demanded by modern industry, only sound potatoes may be used. This means that a considerable amount of sorting and trimming must be done in order to upgrade even good cull potatoes. Sorting of cull potatoes for potato flour is shown in Fig. 94.

If a starch operation is nearby, the cull stock may be conveniently upgraded by sorting before the peeling operation. By removing the potatoes that are not acceptable for flour manufacture at this point, the potatoes are not subjected to any heat treatment and it is therefore possible to divert them to starch manufacture, where the diseased or rotten material can be completely separated from the starch granules. Otherwise, such material is simply discarded.

Courtesy of Rogers Bros. Seed Co.

FIG. 94. SORTING RAW POTATOES IN THE PREPARATION OF POTATO FLOUR

In recent years the potato starch and flour industries have been affected by the Government subsidy program. Under this price support program, payments are made to farmers diverting U. S. No. 1 or No. 2 grade potatoes from the fresh market. In order to qualify, none of these may be converted to products that compete with fresh potatoes, hence, only flour or starch may be manufactured from them. In operation, the potatoes, either culls, graded lots, or field run, are sampled at the point received by the processor to determine the fraction of the load that qualifies for the additional payment. The flour or starch processor operating under

the diversion program is later reimbursed for this amount. These payments although not large, ranging from 30 to 50 cents per hundredweight of potatoes, have been effective in removing surplus potatoes from the market and in promoting more orderly marketing. The diversion payments are usually higher at the beginning of the season in order to encourage early diversion of surplus potatoes to flour, starch or feed-lot uses.

Peeling

Steam peeling is the preferred method in most of the plants manufacturing flour today. Both continuous and batch-type peelers are used. The washing and trimming steps are similar to those used in any other processing industry, with one exception. Because of the "scalping" action of the auxiliary rolls on the drier, it is possible to tolerate a larger amount of peel remaining on the potato than in most other potato processing operations. The potato, however, must be trimmed free of all rot, green end, and other types of discoloration. Trimmings that are removed after peeling cannot be used in starch manufacture, as the starch has been partially gelatinized.

Cooking

A well cooked potato is required for the "flaking" operation. Some plants have used a batch pressure cooker for this purpose. The simplest form of this type of cooker consisted of a cylindrical iron tank with a cone-shaped bottom for drainage. The tank was fitted with a perforated false bottom and openings for introducing and removing the potatoes. Potatoes were normally cooked about 15 to 20 minutes using 15 lb. per sq. in. steam pressure (Noel 1922).

Continuous draper cookers are now standard in this operation. Stainless steel slats or woven wire belting are used to convey the potatoes through the cooker. Using steam at atmospheric pressure introduced above and below the potatoes, 45 minutes to 1 hour is required for adequate cooking of the potatoes.

Drying

The cooked potatoes are then conveyed or dropped to the top spreader roll of the single drum drier. A screw conveyor is used on the top of this drier to distribute the potatoes uniformly across the surface. An opening of $^1/_8$ to $^1/_4$ in. is usually desired between the spreader rolls and the drying surface. The cooked mashed potato forms a coating on each spreader roll which in turn deposits the potato solids on the hot drum surface (see Fig. 95).

Each flour drier is operated by one man who controls the distribution of mash from the top roll to the succeeding lower rolls. In this process,

Courtesy of Rogers Bros. Seed Co.

FIG. 95. MANUFACTURE OF POTATO FLOUR

Sheet of dried potato solids being removed from drum drier by doctor knife.

any peel fragments remaining on the potatoes are collected on the bottom roll of the drier. The operator then removes this material from the bottom applicator roll. The use of three or four spreader rolls effectively removes most of the peel fragments remaining in the cooked potato.

Extremely rapid drying is possible with this equipment and evaporative rates of 18 lbs. of water per hour per sq. ft. of drying surface are common. At a speed of 6 r.p.m. and 100 lbs. steam pressure, a production rate of 5.25 lbs. per sq. ft. per hr. is achieved when drying high solids potatoes. A drier $3^1/_2$ ft. in diameter by 10 ft. long will produce daily 14,000 lbs. of dried material at 7 per cent moisture under these conditions.

The dried sheet of potato solids is removed from the drum surface by a doctor knife held in contact with the drum. It is then normally fed by a screw conveyor into the intake of a fan and conveyed by air to the milling system. Any remaining peel fragments are removed here. The thin flakes are comminuted in some form of beater or hammer mill and then screened to the desired size.

Two types of potato flour are common to the industry. Granular potato flour is normally used in operations where freedom from lumping is desired. The bulk of the potato flour, however, is sold as fine flour, screened through 7xx cloth. Typical screen analyses of these grinds are shown in Table 48.

TABLE 48

TYPICAL SCREEN ANALYSES OF POTATO FLOUR

Screen Size (U. S.)	Granular	Fine
30	0.1	..
40	9.0	..
80	70.2	0.6
100	..	20.3
120	..	9.6
200	..	36.3
Pan	20.7	33.2

A novel method for the production of potato flour was tested in Idaho some years ago. The cooked potatoes were mashed and the skins removed by a sieving operation. The mashed potatoes were then slurried with water and the mixture spray dried. Several advantages were claimed for this process, but it was never developed commercially.

COMPOSITION

Obviously, the composition of potato flour will reflect that of the parent potato, as little is added or subtracted in processing except water and peel. Table 49 shows the average composition and range of composition of flours produced from potatoes grown in various areas during the 1948 emergency program (Treadway *et al.* 1950).

A complete analysis of several samples of cooked peeled potato flour made from Idaho Russet potatoes is shown in Table 50.

At the present time potato flour is made chiefly in two areas in the United States. In Idaho, the main crop of Idaho Russet potatoes has a high content of solid matter (average 22 per cent) and has a low percentage of carotenoid pigments. Flour processed in the Red River Valley area of North Dakota-Minnesota is made primarily from Cobbler and Pontiac varieties, and will contain less starch and a higher degree of pigmentation. Both types of flour are used to advantage in the baking industry, but it is not recommended that they be used interchangeably, as their water absorption values may vary considerably.

USES

The use of potatoes in bread making goes far back into history. Bakers have traditionally used peeled, cooked and mashed potatoes to impart

TABLE 49

AVERAGE COMPOSITION AND RANGE OF COMPOSITIONS OF FLOURS PRODUCED FROM POTATOES GROWN IN VARIOUS AREAS (MOISTURE-FREE BASIS)[1]

Area→	Northeast	South	West	Average
No. of samples	22	7	59	96
Carbohydrate (assimilable)				
Per cent av.	77	78	79	78
Range	73–82	73–81	71–84	71–84
Protein (Nx6.25)				
Per cent av.	11.24	11.29	9.44	10.38
Range	9.56–13.50	10.94–11.75	7.94–13.31	7.13–13.31
Total ash				
Per cent av.	4.46	4.38	4.47	4.50
Range	2.79– 5.35	4.21– 4.54	3.29– 5.96	2.97– 5.96
Acid-insol. ash				
Per cent av.	0.05	0.03	0.06	0.07
Range	0.01– 0.13	0.01– 0.07	0.01– 0.07	0.01– 0.70
Crude fiber				
Per cent av.	1.17	1.17	1.17	1.18
Range	0.9 – 2.3	1.2 – 2.2	0.4 – 3.4	0.4 – 3.4
Fat				
Per cent av.	0.1	0.2	0.3	0.3
Range	0.1 – 0.3	0.1 – 0.3	0.0 – 0.7	0.0 – 0.7

[1] From Treadway, Willits, Heisley, Ross, and Osboyne (1950).

TABLE 50

CHEMICAL ANALYSIS OF TYPICAL COOKED POTATO FLOUR MADE FROM IDAHO RUSSET POTATOES

Analysis	Sample 1	Sample 2	Sample 3	Sample 4	Average
	Per cent	Per cent	Per cent	Per cent	Per cent
Moisture	7.5	8.02	7.18	6.81	7.38
Ash	3.32	2.99	3.20	3.79	3.32
Protein (Nx6.25)	8.13	6.69	7.97	7.81	7.65
Fat (acid hydrolysis)	0.45	1.03	1.39	1.22	1.02
Crude fiber	1.63	1.40	1.58	1.67	1.57
N-free extract	78.97	79.87	78.68	78.70	79.05
	P.p.m.	P.p.m.	P.p.m.	P.p.m.	P.p.m.
Silicon	29	20	78	164	72
Calcium	364	219	295	395	343
Magnesium	1,081	966	1,016	1,122	1,046
Sodium	726	174	401	354	413
Potassium	6,301	14.131	15,915	18,589	13,734
Iron	120	66	260	113	139
Copper	8	3	11	12	8.5
Phosphorus	1,894	1,524	1,820	1,816	1,761
Chlorine	1,325	1,177	1,227	1,724	1,363
Total sulfur	1,373	1,068	1,190	1,454	1,271

potato flavor and improve retention of freshness in their bread. Before compressed yeast came into general use, many bakers used as leavening agent a "ferment" of mashed potatoes, cooked flour, and yeast. Potatoes have long been recognized as an excellent yeast food. Not only have they been employed in the home and the bakeries to promote yeast fermenta-

tion, but potato juice and mashed potatoes are well established among laboratory workers as nutrients for fermentations in general.

Potato bread became common in Europe during the last century, and bakers who migrated to the United States from these countries brought with them the technology of potato bread production.

Most of the carbohydrate in cooked potato flour is starch, all of which is gelatinized and in rather soluble form. The protein present is also mostly soluble. Valuable mineral substances, particularly the potassium, magnesium and phosphorus, essential in stimulating yeast growth, are present

TABLE 51

TYPICAL WHITE BREAD RECIPES USING POTATO FLOUR

	White Bread		Potato Bread	
	Lbs.	Oz.	Lbs.	Oz.
Sponge				
Flour	65	..	65	..
Water	35–38	..	35–38	..
Yeast	2	..	2	4
Yeast food	..	6	..	6
Dough				
Flour	35	..	35	..
Potato flour	2	..	6	..
Water	28–30	..	34–36	..
Salt	2	4	2	4
Milk	3	..	0	..
Lard	3	..	3	..
Sugar	6	..	8	..
Mold inhibitor	..	4	..	4

in amounts adequate for vigorous fermentation. The value of active fermentation in bread cannot be over-emphasized. A vigorous evolution of carbon dioxide is required to give the desired porosity and texture in bread. Less volatile substances that remain in the final loaf and contribute to its flavor and aroma are also produced during fermentation. The constituents of potatoes are recognized as outstanding among bread ingredients for their ability to stimulate growth of yeast cells and activate fermentation of sugar (Treadway 1949).

The generally accepted level of potato flour in "potato bread" is six per cent. That is, six parts of potato flour are added to each 100 parts of wheat flour. Larger quantities are seldom found desirable. In many respects, this bread is unsurpassed for keeping qualities. The acceptance of potato bread is based largely on geographic location; some areas prefer its moist quality and some do not.

The largest volume of potato flour is used at somewhat lower levels in regular white, whole wheat and rye breads. At levels of 2 to 3 per cent, it helps materially to preserve freshness, due to the increased water

absorption afforded by the potato flour. For example, when adding 2 parts of potato flour to the regular formula (100 parts wheat flour), $2^{1}/_{2}$ parts additional water may be added. Laboratory studies have shown that the absorption of water increases in direct proportion to the amount of potato flour used.

Typical recipes for regular white bread containing 2 and 6 per cent flour are shown in Table 51.

It is customary in the industry to add the potato flour to the dough as shown in the foregoing recipes. In the test results presented in Table 52, illustrating the effect of potato flour on bread quality, it was added to the sponge.

TABLE 52

EFFECT OF POTATO FLOUR ON BREAD QUALITY[1]
(Fine Flour Added to Sponge in Quantity Shown)

Identity	Perfect Score	A	B	C	D	E
Quantity of potato flour	..	Control	2%	2%	3%	4%
Fermentation, hrs.	..	4	4	$3^{1}/_{2}$	$3^{1}/_{2}$	3
Exterior score:						
Volume	10	9	9	9	9	9
Crust	2	2	2	2	2	2
Symmetry	5	4	4	4	4	4
Break and shred	3	3	3	3	3	3
Interior score:						
Grain	20	16	17	17	18	18
Texture	20	16	17	18	17	18
Aroma	15	13	14	14	14	14
Flavor	10	8	9	9	9	10
Crumb color	15	14	14	14	14	14
Total	100	85	89	90	90	92
Compressibility, per cent	72	48	49	50	51	54
Toasting quality	..	Last	..	..	Second	First

1 From Doty Technical Laboratory, Kansas City, Mo.

The recent nation-wide introduction of potato crackers was an indication that the use of potato flour by the baking industry is not confined to bread alone. This special cracker, resembling a potato chip in texture and flavor, contains 12 to 20 per cent potato flour. The use of potato flour in soda, graham and other crackers offers a number of advantages, including more complete fermentation, greater bloom and flavor intensification (Kroll 1955). In addition, potato flour is used to advantage in all types of pastries, yeast raised doughnuts, cakes, and cake mixes.

Perhaps one of the largest, virtually untapped outlets for potato flour is the cookie industry. Recent studies made by independent baking laboratories indicate substantial improvements when up to five per cent is

TABLE 53

EFFECT OF POTATO FLOUR ON SUGAR COOKIES

Potato flour, per cent	0	1	2	3	4	5
Total score	87.5	87.5	88.68	89.08	90.50	90.62
pH Value	7.8	7.7	7.6	7.55	7.55	7.30
Diameter, cm.	9.36	9.41	9.45	9.55	9.55	9.60
Thickness, mm.	10.5	...	10.5	10.2	10.0	10.0
Area increase, per cent	51.20	53.33	54.62	57.91	57.91	59.56
Breaking point, Gm.	1,087	1,079	1,022	998	978	948
Color:						
Red, per cent	35	37.5	38.0	39.0	39.0	39.5
Yellow, per cent	25	22.5	21.5	19.5	19.5	18.0
Black, per cent	26	29.0	29.5	31.5	31.5	33.5
White, per cent	14	11.0	11.0	10.0	10.0	9.0

added to all standard type cookies. An example of these tests is shown in Table 53. In addition to the differences shown in this table there was a significant improvement in the bloom, color of crust, volume, texture, flavor and eating quality (Glabau 1958).

Another major use of potato flour is as a breading meal. Some attempt has been made to market this material on a retail level but the market was not appreciable. Frozen fried chicken and sea food are now breaded commercially with potato flour.

A partial list of other end products containing potato flour would include dehydrated soups, frozen pie fillings and crusts, baby animal feed, and many items where the flour is used as a combination thickener-flavoring agent, such as gravies, sauces and baby foods.

OUTLOOK

There are several critical problems facing the manufacturer of potato flour today. In a process where over 50 per cent of the cost of the final item is represented by the raw materials, the rise in cost of this material can be disastrous. In the baking industry, where over 90 per cent of the flour is used, it is competing with lower priced wheat flours and other ingredients.

Per capita consumption of bread has decreased during recent years. However, part of this decline in consumption of bread is due to the emphasis on dieting and weight reduction today and the competition of more glamorous foodstuffs. It would seem that by offering more flavorful varieties of breads and improved freshness stability, potato flour should assume more importance in the baking industry.

The last problem and perhaps the most serious to the industries is that of the chemical softener which is being used in ever-increasing amounts by the baking industry. These materials are approved for use in bread and are easier and cheaper to use than potato flour; hence their popular-

ity is increasing. They are supported by some of our largest chemical manufacturing companies, and have all the advantages of well-organized advertising campaigns.

The manufacturer of potato flour must look to new markets and methods of product improvement, to meet these challenges to his existence.

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William F. Talburt

Canned White Potatoes

Potatoes are canned in practically all of the major growing areas of the United States, with the industry most heavily concentrated in the early producing states. California and Maryland lead in the volume of potatoes canned. Approximately 60 per cent are produced west of the Mississippi River.

Slightly more than 3,000,000 cases of canned potatoes were packed in each of the last three years according to the best available statistics. The actual pack may have been substantially larger than is indicated by these figures since the production of many numerous small packers may not have been reported. Potatoes in several different forms, including whole, diced, sliced, strips, and julienne, are processed. However, whole potatoes, usually smaller than $1^1/_2$ in. in diameter, make up the greatest part of the potatoes that are canned.

Production of canned potatoes has been rising rather steadily during most of the post-war years, principally because of the increasing demand for convenience foods. In fact, canned potatoes are perhaps the most convenient and most quickly prepared of any of the various processed forms of potatoes. Figures on production of canned white potatoes in several recent years by can sizes are given in Table 54.

Very little information is reported in the literature about the early development of this industry. The first potatoes canned in the United States are reported to have been packed in Maryland during the 1920's. During the next two decades production was gradually extended to other areas. At the beginning of World War II the industry was still quite small but grew rapidly during the war years as a result of demand for canned potatoes for the Armed Services and for distribution by the Food Distribution Administration.

The first references to research conducted on canned potatoes appeared in the early years of World War II. An official publication of the Great Britain Division of Food Preservation (Anon. 1942) appeared in 1942 in which the use of firming agents in canned potatoes is described. The Food Distribution Administration specifications for canned white potatoes were issued in 1943.

Hirst and Adam (1943) studied the effects of variety and soil on the suitability of potatoes for canning. Adam (1944) reported that the ascorbic acid content of commercially canned potatoes ranged from 2 to 14

mg. per 100 gm. and that it fell from about 10 mg. in late autumn when freshly harvested potatoes were used for canning to about 3 mg. in early summer packs of old potatoes. Hirst and Adam (1945) outlined a method for processing and for laboratory examination of canned potatoes. They mentioned that the use of calcium chloride causes a loss of about 20 per cent of the ascorbic acid present and that added calcium chloride results in lower and somewhat less variable drained weights.

Table 54

PRODUCTION OF CANNED WHITE POTATOES[1]

Can Size	Actual Cases 1955	1956	1957
48/8	87,965	109,832	106,913
24/300	801,085	841,520	1,055,847
24/303	1,859,543	1,923,935	2,028,473
6/10	347,598	419,843	502,245
Misc. Tin and Glass	52,545	50,612	52,227
Total	3,148,736	3,345,742	3,745,705

[1] Source National Canners Association, Division of Statistics.

Rhodes and Davies (1945) reported on the control of texture of canned potatoes by the use of calcium chloride. They recommended soaking potatoes in a two per cent solution of calcium chloride for one hour, thorough washing in cold running water to remove excess salts, and then processing in the usual way. This procedure was reported to give satisfactory firming of the potato, and to introduce 0.06 to 0.14 per cent of calcium chloride into the product. This amount was found by the authors to be undetectable by taste and below their threshold value of 0.2 per cent. They also postulated that the firming effect of calcium ion was due to its reaction with constituents of the middle lamella to form calcium pectate. Adam (1950) found that the pH of 20 samples of commercially canned potatoes ranged from 5.4 to 6.2. Gould *et al.* (1951) found that canned potatoes were very susceptible to off-flavor from certain agricultural spray residue when tasted three months after canning.

RAW MATERIAL REQUIREMENTS AND SELECTION

Potatoes are canned in nearly all of the major producing areas of the United States with the exception of Idaho. The potatoes used are not specifically grown for canning but are primarily the smaller sizes of potatoes not suitable for fresh market. In most instances, these potatoes are harvested, moved to packing sheds, separated from the larger sizes which go to fresh market, and are then transported directly to the canneries where

they are processed within a few days. Under such conditions the processing season usually does not exceed 60 days and is only a minor product for canners producing other items. About the only exception to this method of handling is found in Maine where potatoes are canned from September 15 to June 15 as they are removed from the storage cellars on their way to fresh market. Here again the small sizes that are not suitable for fresh market are sent to the canners. Varieties in general use and approximate season for canning potatoes in the several producing areas are given in Table 55.

Table 55

CANNING SEASON AND VARIETIES OF POTATOES USED FOR CANNING

Area	Varieties	Season
Eastern Shore (Md.-Va.-N. J.)	Cobbler, Katahdin	June 1 to August 15
California	White Rose	May 1 to June 15
Florida	Pontiac, Sebago	December 1 to July 1
Maine	Chippewa, Kennebec, Katahdin	September 15 to June 15

Since prices received by canners for canned potatoes are generally quite low as compared with a number of other canned items, it is generally felt that processors cannot afford to pay a very high price for potatoes. In California the price in most recent years for the small sizes of potatoes has been about $1.00 per hundredweight delivered to plants within a 300-mile radius of the producing areas. This price is somewhat independent of the prices received by growers for potatoes going into the fresh market. The latter may fluctuate markedly and be several times greater than the price of the canning sizes. Since approximately 2 to $2^1/_2$ cases of canned potatoes can be obtained per hundred weight of potatoes, the cost of the potatoes at $1.00 per hundred weight would be about $0.40 to $0.50 per case.

One of the primary requisites of a good canning potato is that it should not disintegrate or slough during processing. Immature potatoes with low solids content and with a specific gravity of less than 1.075 can generally be canned without disintegration or sloughing during processing even without the use of calcium salts. Sloughing can usually be prevented in specific gravity lots of 1.075 to 1.095, with the recommended amounts of calcium chloride. Potatoes with specific gravities in excess of 1.100 are likely to slough excessively even with added calcium salts.

Incoming shipments of potatoes for canning should be examined to determine their suitability for canning. Specific gravity should be checked by immersing representative samples in salt solutions made up to proper

concentration. Samples that float in a salt solution of 1.075 specific gravity are likely to can satisfactorily without added calcium salts; while those that sink in 1.095 specific gravity solution may slough even with added calcium. Specific gravity of salt solutions can be checked with a hydrometer or solutions of desired strength made up by determining from a salometer or other suitable table the amount of salt to be added to a given amount of water. Actual canning tests should also be run with and without added calcium chloride in order to be absolutely sure how the potatoes are going to behave during processing.

As the harvest season progresses in a given area, maturity of the potatoes usually increases with a corresponding rise in specific gravity and solids. Generally greater sloughing and disintegration of the canned product are encountered as the season progresses until unsuitability of raw material necessitates termination of canning. This is not the case in Maine where the potatoes are generally fully mature before harvest. In the latter area late storage potatoes that have become somewhat spongy and rubbery are less subject to sloughing than those processed earlier in the season.

If the sugar content of potatoes is high as a result of low temperature storage, or other causes, the canned product may be somewhat discolored. During certain seasons potatoes from a number of Eastern growing areas have been found to be susceptible to discoloration or darkening when heated. The reason for this type of discoloration is not known. There is some indication that this is becoming a more serious problem.

Potatoes for canning should also be carefully inspected for insect injury, mold damage, physiological changes, physical injury, bacterial diseases, and miscellaneous defects such as sprouting, net necrosis, and excessive immaturity. If 15 per cent or more of the potatoes show defects or damage, the additional labor cost for inspection and trimming may make the cost of canning such potatoes prohibitive.

When potatoes are to be stored several days before canning they should be held in a cool area away from direct light in order to avoid losses through rot and to prevent "greening." This green discoloration is not readily removed by normal peeling and may contribute a bitter taste to the canned product. Potatoes should be stored in a well-ventilated area in order to minimize losses of potatoes through bacteriological and undesirable physiological changes.

Freshly harvested potatoes yield a better quality canned product, are easier to peel, and require less labor for inspection and trimming.

CANNING PROCEDURE

The following procedure is normally used for canning potatoes. Equipment used to accomplish the various operations varies widely but for the

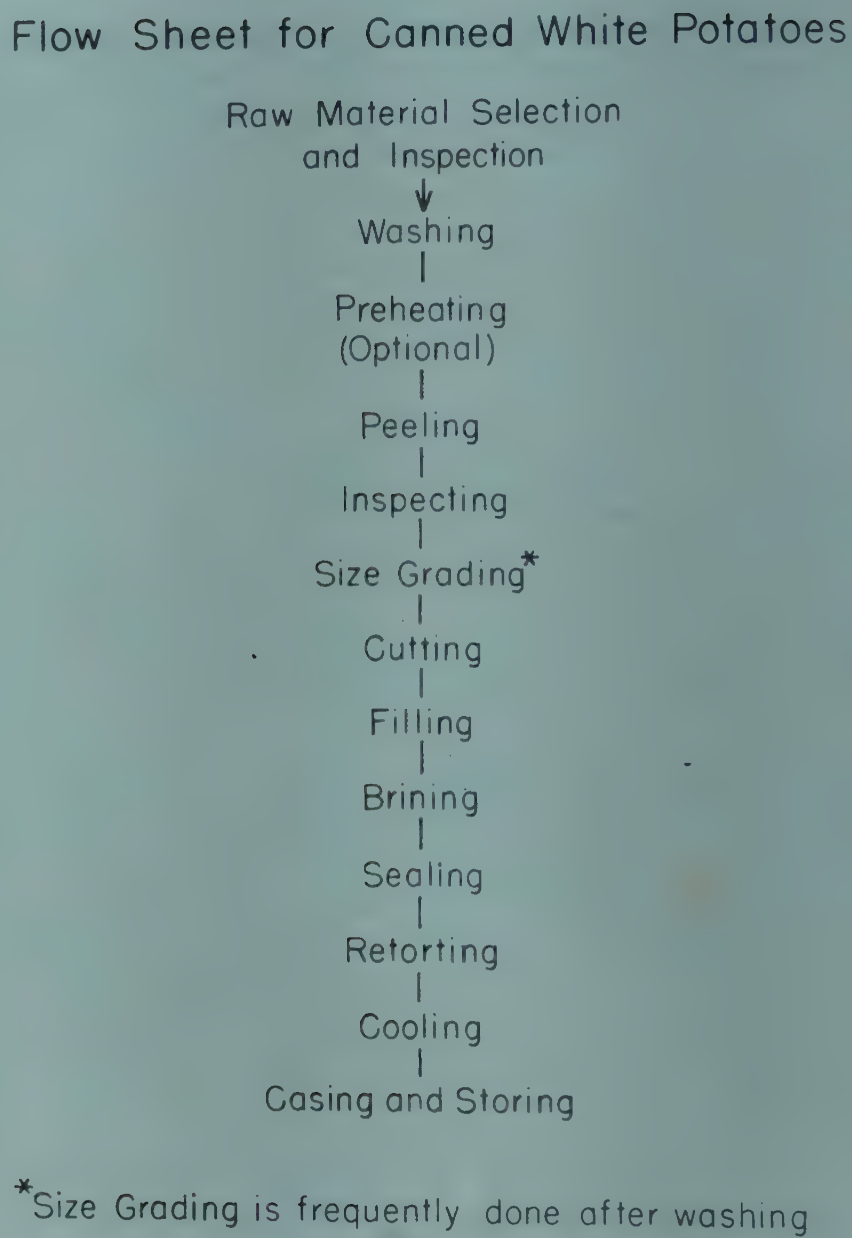
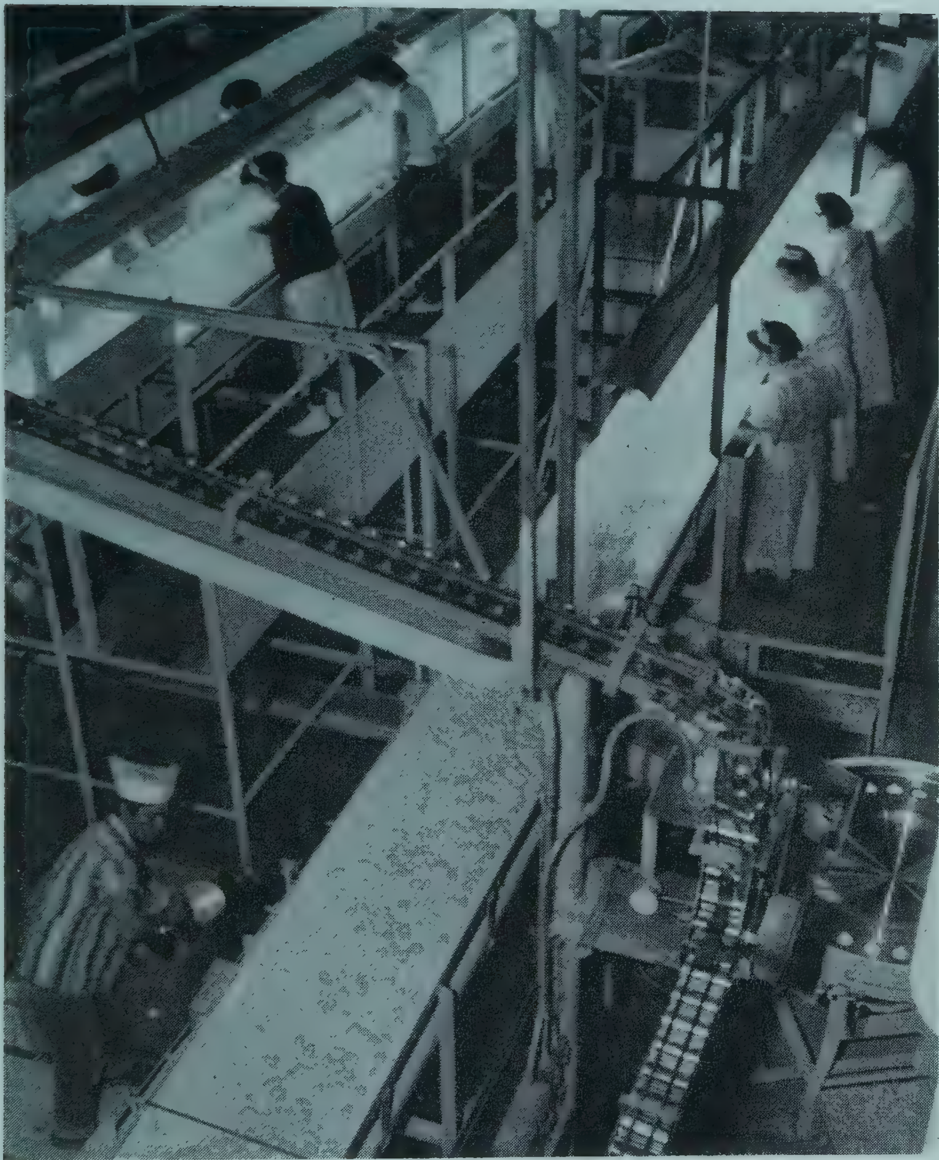


FIG. 96. SEQUENCE OF OPERATIONS USUALLY USED IN THE CANNING OF WHITE POTATOES

most part, the sequence of operation has been fairly well standardized over the past ten years. Fig. 96 is a flow sheet of the process which is normally used in canning white potatoes. Fig. 97 is a general view of one of the most modern potato canning plants in the West.

Cleaning

Before peeling it is essential that surface dirt be removed from the potatoes to avoid carrying dirt and grit over into the peeling equipment



Courtesy of Bakersfield Foods Co., Inc.

FIG. 97. GENERAL VIEW OF MODERN POTATO CANNING PLANT SHOWING PEELER AND WASHER, INSPECTION BELTS, AND FILLING OPERATIONS

where it may cause serious equipment problems. All handling of potatoes through initial washing should be conducted in an area separated from that used for subsequent canning steps. Reel-type washers with strong sprays of water to loosen and remove adhering dirt are usually used. Spiral flights may be employed to control the time potatoes are retained in the washer. Where stones constitute a problem, they are removed by discharging potatoes from the washer into a trough with rapidly flowing water moving over a set of wooden riffles properly spaced at the bottom

of the trough. The potatoes are carried along by the stream of water and any stones are caught on the riffles and remain behind.

Preheating

In some plants potatoes are preheated in water prior to peeling in order to reduce the heat load on the peeler, thereby increasing its capacity. This is especially effective during cold weather when potatoes may be below 50°F. as they start through the plant. This operation is also said to be effective in preventing enzymatic discoloration and other darkening which may occur when potatoes are taken directly from cool storage and subjected to high temperature peeling.

Peeling

Lye, steam, and abrasion peeling and combinations of these are used in the canning of potatoes. These types of peeling are discussed in detail in Chapter 9 (see also pp. 206 to 222) but some special problems peculiar to canning are discussed here. Both batch and continuous high pressure steam-peeling equipment are used. Batch steam peelers consist of a cylindrical drum equipped with a side-opening port and lid and a mechanism for rotating the drum slowly. Potatoes are filled into the drum which holds 500 to 1000 lbs. of potatoes. The lid is locked on the port and steam at about 100 lbs per sq. in. pressure is let into the chamber. Care must be taken to insure venting of any trapped air. The drum is slowly revolved during this time to promote even heating and to assist in removing peel loosened by the action of the high temperature steam. After a short interval the drum is stopped, the pressure is released, and the potatoes discharged by inverting the peeler and allowing the potatoes to fall into water which transports them to the washer. Retention time will vary with temperature, variety, and condition of the potatoes. Continuous high pressure steam peelers are quite economical in their steam requirements. Peeling losses are said to be quite low, but the initial installation and maintenance costs are high.

Several types of lye peelers, including reel or drum types and draper belt in tank types, are in general use. Concentration of lye in the solution may vary from 5 to 15 per cent. The temperature of the solution is usually maintained near the boiling point although in some cases the temperature may be as low as 180°F. Some canners feel low temperatures are preferable in that they result in lower peeling losses and prevent too great a penetration of heat into the potato. Excessive heat penetration causes discoloration in the area immediately adjacent to the "heat ring" in some lots of potatoes that are subject to enzymatic darkening.

A heavy cooked layer of gelatinized starch on the surface of the peeled potato may also interfere with the action of calcium chloride in preventing sloughing. Excellent results are obtained with lye peeling even with potatoes having deep set eyes.

Provision is made to control the immersion time usually by means of a variable speed drive on the peeler. Temperatures near the boiling point are usually used where lye concentrations are 5 to 10 per cent. With higher concentrations, effective peeling can be accomplished at temperatures of 200°F. or below. The advantages of using lower temperature and high concentrations of lye are questionable unless discoloration of peeled product is a problem.

Immersion time for satisfactory peeling depends on the condition and size of potatoes and the temperature and strength of the lye solution. Usually new potatoes with thin skins are easier to peel than older ones although this is not always the case. In order to maintain the best operating conditions, the concentration of lye in the peeler should be checked and lye or water added often enough to ensure a reasonably uniform concentration of lye during the operation. Some plants check the lye concentration by titrating with standard acid solution.

Abrasion peelers are sometimes used by small processors where the size of the operation does not justify more expensive lye or steam peelers. Peeling losses are much greater with this type of peeling than with either steam or lye peeling. Abrasion peeling is sometimes used after potatoes have been lye or steam peeled and washed in order to give the potatoes a smoother appearance by removing the "pebbled" surface that is frequently found on the peeled potatoes. Whether using lye or steam for peeling, it is essential that the product be discharged immediately into a washer equipped with high pressure water sprays so that the peel can be removed before it has a chance to harden. Otherwise the peel can be removed only with great difficulty. Reel type washers are generally used with water sprays operating at 80- to 100-lbs. per sq. in. pressures. Sprays should be regulated so that the skins are removed by the water and by the tumbling action of the potatoes but should be regulated so that they do not cause excessive pitting or roughening of the surface of the potatoes. Corrugations and spiral baffles or flights are usually built into the reel to control the forward motion of the potatoes and assist in the removal of the skin. Lye which is not removed from the potatoes during washing will cause yellowing during subsequent operations.

Inspection and Trimming

Only a minimum amount of trimming can be used on this low cost product (see also p. 357). While some trimming to remove shallow un-

peeled eyes, small pieces of skin, and other defects may be advantageous, many canners feel that it is cheaper to sort these from the cleanly peeled potatoes and send them through the lye peeler again. Fig. 98 shows the inspection of potatoes after peeling and washing. Since smaller sizes of white potatoes bring a premium price and since the raw material cost is relatively low, such a practice is generally considered to be more economical than trimming. Excessive trimming of whole potatoes also affects the grade of the final product.

Size Grading

If the potatoes have not been size-graded before peeling, they are sized after inspection. Equipment should be designed and operated so as to minimize bruising. Perforated belts and screens, rubber spools, and diverging belt graders are used in sizing potatoes.

Where potatoes are sized prior to peeling and only one size run at a time, considerable size variation will be found in the peeled potatoes due to the differences in the way they react during the peeling operation. Where potatoes are put through the lye peeler a second time rather than trimming, these size differences become even greater.

A much more uniformly sized product is obtained if potatoes are sized after peeling, but unless several lines are available to handle the various sizes simultaneously, it is necessary to accumulate and hold certain size groups while others are being canned. These potatoes should be held in a 1 to 2 per cent salt solution in order to prevent discoloration. Holding time should be as short as practicable since off-flavors and adverse texture changes may occur. Salt solution is usually washed off the potatoes prior to canning in order to obtain more precise control of salt in the final product.

Cutting

Smaller sizes of potatoes are normally canned whole since they command a premium price. The larger sizes, $1^7/_8$- to 2-in. or slightly larger, may be sliced. Still larger sizes are normally used for diced, julienne and shoe string potatoes. Proper cutting and slicing equipment should be used and the cutting knives maintained in good condition in order to minimize the amount of chips and fines. The small pieces are removed from the product by screening in order to maintain the uniformity of piece size demanded by the U. S. Standards of Grades for Canned Potatoes. Where cut potatoes are to be stored for any length of time, they should be held in a salt solution to minimize undesirable discoloration.

FIG. 98. INSPECTION OF POTATOES AFTER PEELING AND WASHING

Potatoes not completely peeled are removed and passed through lye peeler again.

Filling and Packing

Whole and cut potatoes are filled into the containers by automatic as well as rotary hand-pack fillers. Fig. 99 shows peeled and sized potatoes being filled into containers. Cans made with inside hot dipped or electrolytic plate bodies and inside enamelled electrolytic plate ends are generally recommended. More exact description of the type of containers used are available from any of the can manufacturing companies. The

minimum drained weights, recommended in the U. S. grades for canned white potatoes, are presented in Table 56.

After the potatoes have been filled into the container, either boiling water or brine containing 1.5 to 3.0 per cent of salt by weight should be added to the container in such quantity as to fill the container to the proper level. Where boiling water is used, a salt tablet of proper size is added to the container prior to sealing.

FIG. 99. SEMI-AUTOMATIC EQUIPMENT USED IN SOME PLANTS FOR FILLING POTATOES INTO CONTAINERS

The standards of identity for this product also permit the addition of calcium in the form of calcium chloride, calcium sulfate, calcium citrate, monocalcium phosphate, or any mixture of two or more of these salts. The amount of calcium salt used must be in such quantities that the total calcium content does not exceed 0.051 per cent of the net weight of the finished product. Calcium chloride is usually used because of its ready solubility. However, calcium citrate has been reported to impart less bitter taste to the product than calcium chloride.

Salt tablets, calcium tablets, and tablets containing salt and calcium compounds in the right proportions for adding to canned white potatoes

are available commercially for all of the common can sizes. Where salt and or calcium compounds are added to the container as a brine, close control of the amount added is not possible due to variation in the ratio of solid to liquid between containers. Use of proper tablets makes possible much closer control of salt and calcium addition.

Table 56

RECOMMENDED MINIMUM DRAINED WEIGHTS FOR CANNED WHITE POTATOES

Can Size	Recommended Minimum Drained Weight	Suggested Label Net Weight	
	Oz.	Lbs.	Oz.
303 x 406	[illegible]	1	0
307 x 409	13.0	1	4
401 x 411	19.0	1	13
603 x 700	74.0	6	6

Calcium tablets should be placed at the bottom of the container and the container inverted after sealing, or the tablet should be placed in the top of the container after filling. This permits the tablet to dissolve and the calcium salts to settle and diffuse throughout the liquid rather than remain in the lower part of the container. It is essential that the calcium salts be reasonably uniformly distributed throughout the container or sloughing of the potatoes may occur during subsequent heating. Abrasion peeling to remove part of the cooked gelatinized starch that is formed in high temperature lye or steam peeling allows more rapid penetration of calcium chloride and reduces the tendency of the potatoes to slough during subsequent processing.

Closing

Closing temperatures of 160°F. or above should be maintained if ordinary closure is to be used. If the temperature drops below 160°F., steam flow or vacuum closure is used in order to obtain desirable can vacuum.

Processing

The processes recommended for canned white potatoes by the National Canners Association in their Bulletin 26L, "Processes for Low-Acid Canned Foods in Metal Containers," are presented in Table 57.

Cooling

After processing, cans are water-cooled promptly to about 100°F. Casing and stacking of the packed can at temperatures in excess of 100°F., particularly if stacked in large blocks which do not permit circulation of air, may result in quality deterioration known as "stack-burning." If the

temperature is much lower than 100°F., the cans may not dry properly and external rusting of the containers may occur.

FEDERAL REGULATIONS AND GRADES

Canned white potatoes are covered by a standard of identity under the Federal Food, Drug and Cosmetic Act of 1938. Copies of the complete standards can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C. These standards, issued in 1940 and amended to permit the use of calcium salts in 1949, give the legal definition of the product by its common name and designate the optional ingredients which may be used in the canning of white potatoes. Canners shipping interstate must comply with this standard as well as with state and local regulations for areas in which they operate.

TABLE 57

RECOMMENDED PROCESSING TIMES AND TEMPERATURES FOR CANNED WHITE POTATOES

Can Size	Initial[1] Temperature, °F.	Time (Min.) at 240° F.	Time (Min.) at 250° F.
No. 303 (303 x 406)	70	35	23
	140	30	20
No. 2 (307 x 409)	70	35	23
	140	30	20
No. 2½ (401 x 411)	70	40	30
	140	35	25
No. 10 (603 x 700)	70	50	35
Except Sliced	140	45	30
No. 10 (603 x 700)	70	55	38
Sliced	140	50	32

[1] Initial temperature is the average temperature of the can contents at the time the steam is turned on for the process.

No specific standard of fill has been prescribed for canned potatoes. However, the Federal Food, Drug and Cosmetic Act, applicable to canned foods, states that the container must not be so filled as to be misleading. The containers should be filled as full as is commercially practicable without impairment of the quality of the product. Specific instructions for labeling are also included in the standards.

United States Standards for Grades of Canned White Potatoes have been issued by the Agricultural Marketing Service, U. S. Department of Agriculture, Washington, D. C. Copies of these specifications for grades are obtainable from the Agricultural Marketing Service, Washington, D. C. or from their local offices. These standards for grades, which are not mandatory, describe in detail the factors considered in determining grades and the procedures for ascertaining the rating of each factor.

These grades are quite widely used and serve as a basis for uniform

quality description. Most purchases by Federal agencies are made on the basis of certified U. S. grade standards.

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Robert L. Olson and
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Pre-Peeled Potatoes

The twenty-five year old pre-peeling business is a relatively new and growing segment of the potato processing industry. For this operation potatoes are prepared for cooking, treated with sulfite to prevent discoloration, refrigerated to arrest bacterial spoilage, and delivered at the convenience of customers. The product is relatively perishable but, with care in processing and adequate cooling, may be held for several days under refrigeration and excellent quality maintained. General procedures have been described in technical literature during the past ten years (Olson and Treadway 1949; Ziemba 1954; Feustel and Harrington 1955).

Commercially pre-peeled potatoes are available in most metropolitan areas of the United States. A variety of forms such as julienne strips for French-frying, whole potatoes for general purposes, pre-cooked and shredded for hash-browned potatoes, and par-fried in deep fat for French frying supply the main demand at present in the food service industry. No substantial retail distribution has been developed although in many respects this appears to be a market of considerable magnitude that would allow a many-fold increase in the size of the industry (Garrott 1955).

In the early 1930's in the Boston area, peeled potatoes were made available for purchase by restaurants (Olson and Treadway 1949). They were first supplied in milk cans, the potatoes being submerged in water to reduce discoloration. This bulky package soon gave way to a dry pack of potatoes that had been treated with sulfur dioxide or one of its derivatives to prevent discoloration. In Metropolitan Boston the development has grown to a sizable operation over the years. A rapid expansion in other areas began after World War II when enterprises were initiated in Chicago, San Francisco, New York, and Los Angeles and then generally throughout the country wherever state public health regulations concerning the use of sulfite were not too restrictive. By no means did all of these ventures prosper. However, some of the most successful now in existence began operations in those early days.

It has been suggested that success in a pre-peeling venture requires a population center of at least 100,000 (Garrott and Mercker 1954). In

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1954 there were 120 commercial operations in 32 states and the District of Columbia (Garrott 1955). Some increase since that time has occurred in the number of establishments and a considerable increase in production has been obtained by expansion of existing facilities.

In general, two types of organizations are successfully operating today. Most pre-peeled potatoes are prepared in large well-organized processing plants, using a force of hired labor and processing upward from 200 sacks of potatoes a day. Such plants are highly mechanized to reduce labor costs and have a number of delivery trucks to service customers.

Another type of plant which also is highly significant in pre-peeling is the small family operation which may handle an average of 100 sacks of potatoes a day or less. In such operations, usually no labor is hired, or at most, only one or two permanent employees—the remainder of the labor being provided by the proprietor and his family. In a typical operation, the proprietor and his immediate family will operate a peeling, trimming, and cutting line usually with the assistance of one paid helper who may do much of the heavy lifting and clean up the plant. All equipment is batch operated and cutters are hand fed. Before noon the processing will be complete and the proprietor will make deliveries, possibly with the assistance of a paid salesman in a second truck. In addition, the proprietor will call on new prospects, supervise potato and other required purchases, develop publicity, conduct research activities, supervise quality control, and carry on all requirements of the small business operation.

Pre-peeling operations are generally located in or adjacent to the trade area that they supply so as to be within easy reach of customers. Someone is ready at all times to make an emergency delivery to a restaurant that has had an unusual flow of trade, or to replace a lot of potatoes that has spoiled (perhaps because of neglect on the part of the customer).

Some operations that have been located in a potato growing area some distance removed from the principal market have not been successful. The difficulty of providing prompt, and at times frequent, service may have been the cause of failure in such operations.

Many attempts have been made to develop retail markets. However, commercial applications of the technology of potato pre-peeling have not provided sufficient shelf life to guarantee the quality of product which the American housewife has learned to expect even though laboratory or kitchen trials have clearly shown it to be quite possible to preserve peeled potatoes for two weeks or more (Anderson *et al.* 1954; Anderson and Zapsalis 1957). The higher contamination of food spoilage organisms that comes frequently with plant operations and difficulty in rapidly removing heat from large masses of product have probably been the

causes of this apparent anomaly. There is a possibility that adequate product storage life could be attained in some plants in the industry, if bacteriological sterility were approached—as in a modern dairy—and if a more rapid rate of heat transfer were achieved in the cooling operation.

The advantages to the food service industry inherent in the use of pre-peeled potatoes are convenience and labor reduction in the handling and peeling of potatoes, elimination of waste and its disposal problems, assurance of high quality potatoes with minimum purchasing effort, and a relatively stable price for potatoes throughout the year. It is, thus, evident that pre-peelers are purveyors of service as well as a product of uniform quality (Olson and Treadway 1949; Ziemba 1954).

RAW MATERIAL REQUIREMENTS

The quality requirements of potatoes for pre-peeling must be specified in relation to the ultimate use and balanced against cost of procurement. A high quality potato for mashing or baking is not necessarily most suitable for chipping or French frying. A high cost potato may ultimately be less expensive because a higher yield of premium sized French-fry cuts may be obtained therefrom, or peeling and cull losses may be lower.

Decisions on purchases of raw material have an important effect on commercial operations. Analysis of sales and costs of production should be accumulated to assist in making such decisions. The processor will generally buy in sufficient quantity to justify quality testing of samples from lots available for purchase in order to be sure that his customers will get a product suited to their needs. This is an important consideration inasmuch as the user of peeled potatoes usually buys in such small quantities that pre-testing of quality is not practicable. This, then is one of the major services rendered by the pre-peeler to his customers.

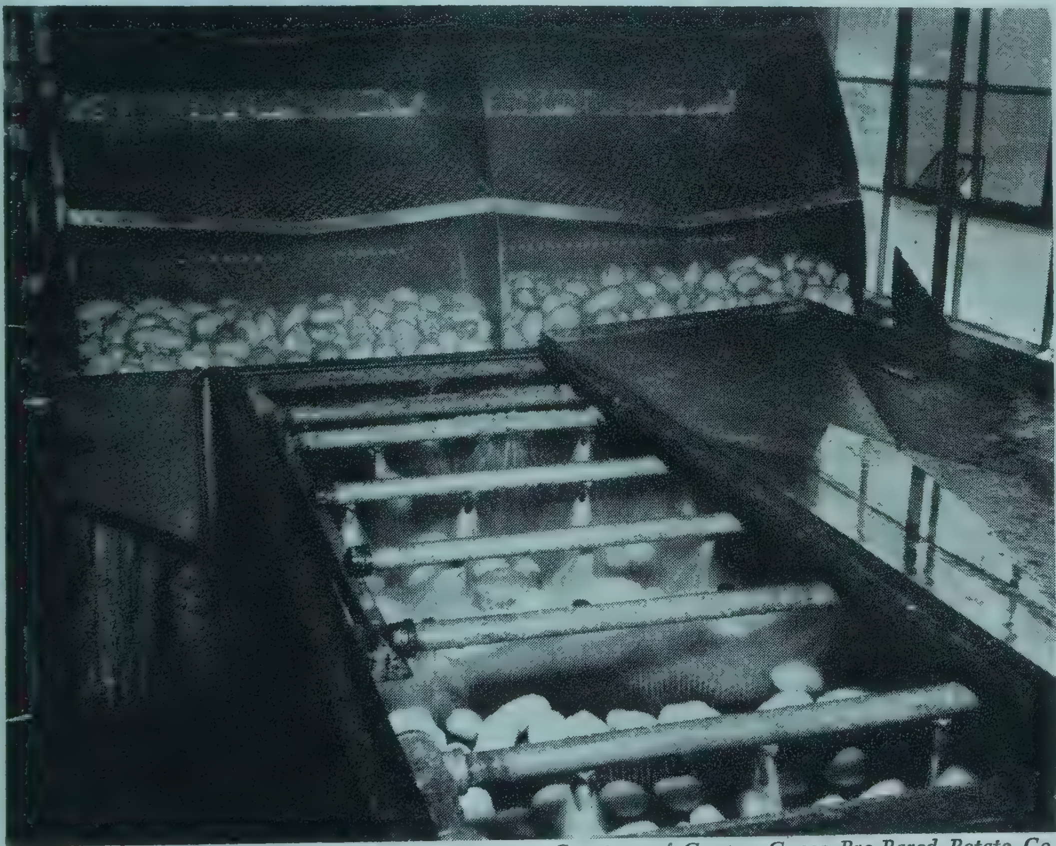
As part of the inspection procedure in selecting suitable potatoes for pre-peeling, a representative sample should be selected and tested for cooking quality. A minimum test would be to cut the potatoes into strips and French-fry them. If they fry to an unattractive dark color because of high sugar content, they cannot be used for this purpose. More elaborate tests would include flavor and color evaluations and a test for quality as boiled and mashed potatoes. The anticipated use of the potatoes of course influences selection of the tests to be performed.

Size, shape, uniformity, and general condition are also important considerations. Large potatoes may be peeled and cut with minimum loss and cost. The desirable long French-fry cuts can be made only from large potatoes. Many pre-peelers have only limited use for the smaller sizes which are generally used as whole or hash-browned potatoes (Harrington *et al.* 1956). Uniformity of shape and size are necessary for efficient peel-

ing and trimming, especially where abrasion peelers are used. The presence of rot, surface cuts, and bruises increases trimming losses.

PEELING

In addition to the general potato peeling problems faced by other processors of potatoes, the pre-peeler is confronted with additional ones. In general it is not feasible to use peeling methods that involve use of heat if temperatures rise above about 160°F., the gelation point of potato



Courtesy of Granny Goose Pre-Pared Potato Co.

FIG. 100. WHITE ROSE POTATOES EMERGING FROM WHEEL-TYPE, LOW-TEMPERATURE LYE PEELER AND PASSING OVER SCRUBBING ROLLS IN A WASHER

starch (Olson and Treadway 1949; Harrington *et al.* 1956). Thus steam peeling and lye peeling in their most usual form will result in surface cooking of the potato to a depth of $^1/_8$ in. to $^3/_8$ in. depending on the severity of the heat treatment. Such a cooked surface presents an unattractive, nonuniform appearance in a cut piece of potato. Furthermore, after such a potato is held for a few days under refrigeration, the cooked surface tends to become permanently toughened. Such potatoes are not suitable for mashing because of undesirable lumpiness in the

product as served. However, the severity of this problem appears to vary greatly with variety and growing area. At least one large pre-peeler of potatoes used batch-type steam peelers for a number of years with out reporting problems of severe quality impairment. However, several processors equipped for steam peeling found it impossible to continue operations and either failed in business or converted to other peeling methods. Abrasion and low-temperature lye peeling are the most widely used peeling methods in use today (Garrott 1955). Small plants generally use batch-type abrasion peelers while larger operators use low-temperature lye peelers or continuous abrasion peelers.

Lye peeling at low temperature has been successfully used for a number of years by processors of pre-peeled potatoes. In plant operations, temperatures below 145°F. are used with lye concentration maintained at about 20 per cent. An integral part of a low temperature lye peeling operation is a well-designed washer for prompt and thorough removal of the lye-affected tissue (Harrington *et al.* 1956). A wheel-type lye peeler and washer used in a large pre-peeling plant is shown in Fig. 100.

The actual cost of pre-peeled potatoes as they are ready to be packaged is greatly affected by the way the peeling equipment is operated regardless of whether lye or abrasion peeling is used. For most efficient operation, the peeling cycle must be varied to compensate not only for differences between lots of raw material, but should also be changed in accord with the price of the potatoes being peeled. When the price of potatoes is low it is more economical to remove a thick layer of potato during peeling so as to reduce the amount of trimming that is required. Conversely, when the cost of potatoes is high, it may be possible to reduce production costs by reducing the peeling cycle even though additional trimming is required as a result of less complete removal of peel. It is difficult to overemphasize the importance of achieving the proper balance between peeling losses and trimming and raw material costs for most efficient operations. This part of the procedure should be studied carefully and accurate records kept inasmuch as this may mean the difference between success and failure in the plant operations.

TRIMMING AND CUTTING

At one time it was common practice to leave a considerable portion of peel on potatoes to be sliced for French frying. The increased surface resulting from slicing and the browning of the product during frying made the small occasional piece of skin on the end of the slice negligible. This practice has been largely abandoned in favor of completely trimmed French-fry cuts. A general view of a pre-peeling plant with trimming belt in the foreground is shown in Fig. 101.

Hand fed cutters are still in rather common use, and result in the greatest yield of long cuts because mechanical cutters do not orient the potatoes so as to obtain the maximum number of long slices. However, the increased labor cost and inconvenience of hand operations have caused most of the larger prepeelers to use mechanical cutters. Where hand fed cutters are used, safety guards should be installed.

Courtesy of Granny Goose Pre-Pared Potato Co.

FIG. 101. TRIMMING LINE. IN BACKGROUND, WHOLE POTATOES EMERGING FROM TANK OF SULFITE SOLUTION ON DRAPER BELT

For a reasonably uniform product cut for French frying, 2 to 10 per cent of the peeled potato is removed in the form of undersized side cuts, slivers and broken pieces. A premium quality product with an even higher loss from irregular pieces is sometimes produced. It is possible, however, to utilize some of this small-sized material, along with potatoes too small to cut, in hash-browned potato stock.

PREVENTION OF DISCOLORATION

To date there has been no published information indicating that commercial color preservation of peeled potatoes has been accomplished without using sulfur dioxide (SO_2) or one of its salts as an active agent. In

many cases where formulations of other reagents have been used in conjunction with sulfur dioxide, the effect has been to alter the degree of acidity of the solution into which peeled potatoes are dipped.

Patent and trade literature have described other active agents which have been effective in experimental trials. These have not been used commercially because of high cost or accompanying deleterious effects on the product quality, e.g., ascorbic acid and adenosine triphosphate are expensive reagents, and severe acid treatment causes potatoes to leak cell sap and imparts an undesirable taste.

Sulfur dioxide has been thoroughly tested for possible toxic effects and in the amounts used in pre-peeled potatoes is acceptable to public health officials in nearly all states.

The use of sulfur dioxide or salts of sulfur dioxide is permitted by the Federal Food and Drug Administration, provided the preservative is not added to conceal damage or inferiority. Proper labeling is required when such foods are destined for interstate commerce and, thus, are under Federal jurisdiction.

Most state and local governments follow Federal provisions relative to the use of sulfur dioxide. However, because exceptions exist, local offices of such agencies should be consulted prior to establishing a pre-peeling plant.

Sulfur dioxide has the advantage of being somewhat antiseptic in addition to its function as an inhibitor of discoloration. In high enough concentrations the sulfite solutions can destroy many of the common food spoilage organisms. Therefore, the treating solutions are relatively sterile. However, in the way that this compound is usually used in treating peeled potatoes, sulfite residues on the product are very small and only serve to arrest in a minor way the development of spoilage organisms that may contaminate the product.

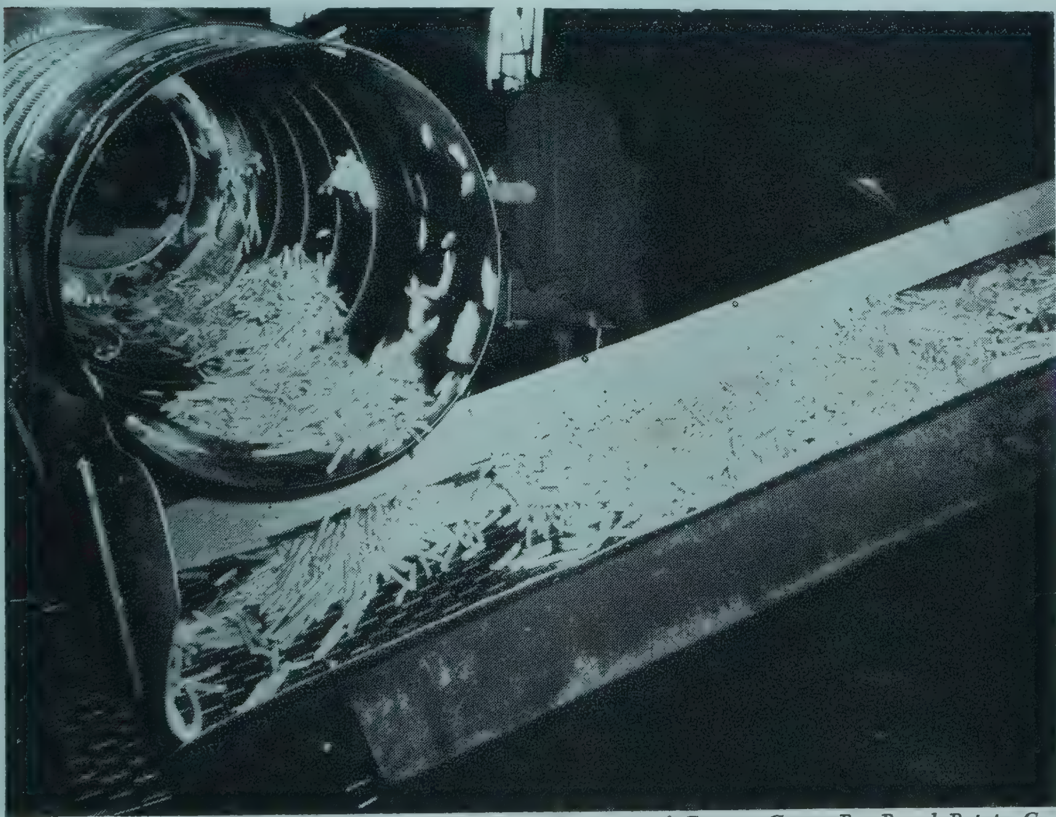
As universally used, the formulation containing a sulfur dioxide source is dissolved in a tank in which peeled or cut potatoes are immersed. After a short treatment they are removed, drained and packaged.

Immersion operations are frequently controlled by a draper belt that conveys the potatoes from one end of the tank to the other and then out to conveyor belts or dewatering reels for draining (see Fig. 102). At least one specially constructed piece of equipment in commercial use impels the product through a round-bottomed trough by means of a helical screw.

Within moderate limits preservation is prolonged as immersion time and concentration of sulfur dioxide in the treating bath are increased. Excessive treatment will cause adverse changes in the product. Objec-

tionable flavor, abnormal appearance, and leakage of cell sap frequently result from over-treatment.

A number of factors should be considered in determining the proper immersion time and sulfur dioxide concentration in the dipping bath (Mullins *et al.* 1953). Variations in tendency to discolor, as well as in cooking quality, total solids, flavor, and other factors, exist among varieties of potatoes and among lots of a variety from different sources.



Courtesy of Granny Goose Pre-Pared Potato Co.

Fig. 102. Dewatering Reel for Sulfite Treated, French-Fry Cuts of Potatoes. Perforated, Stainless Steel Conveyor in Foreground

In general, when lots of a given variety from a given area are obtained, treating conditions need not be altered. However, as storage proceeds or as new varieties and potatoes from other producing areas come into the market, it is frequently necessary to modify the treatment.

By continuous experiment and with the guidance of accumulated experience of the operator, the preservative treatment can be adjusted to raw material changes and seasonal climatic differences in order to keep the amount of sulfite in the product at the minimum level for adequate preservation of color.

The treatment necessary to preserve adequately the potatoes will also

depend in large part on the individual conditions of a processor's facilities. For example, the bruising action of an abrasion peeler may allow a more thorough mixing of the chemical components of the potato that cause discoloration. Prolonged and thorough washing may dilute and dissolve such components so that they are less likely to cause discoloration. Holding the potatoes under water retards discoloration by keeping oxygen from the surface. On the other hand, long exposure to air on the trimming and sorting belts will promote discoloration.

The temperature of the product has an important effect on rate of discoloration, which increases as the product temperature rises. Therefore, temperature of wash water and of treating solution have an important effect on the amount of treatment required for color preservation.

The anticipated storage conditions for pre-peeled potatoes reflect back on the treatment that is required to preserve the product. The higher the product temperature and the longer the storage period, the greater the tendency to discolor, and the more severe the treatment that must be used.

Packaging is important because some materials will limit the exposure of product to oxygen and tend to protect it from discoloration. Vacuum packing has been reported to reduce sulfite requirements to a fourth of that for more conventional packaging (Anderson and Zapsalis 1957).

The requirements of customers also enter into the determination of proper treatment formulation. Customers having inadequate refrigeration or using poor handling practices will require products with stronger preservative treatment or more frequent deliveries than customers who have good refrigeration facilities and use them properly. Factors such as these must be predetermined in a general way in order to establish a satisfactory treatment for a successful pre-peeling operation.

It may be seen, then, that the possibility of a universal optimum formula for color preservation of peeled potatoes is not feasible nor is it necessary. It is possible to present a plan, however, that can be used as a basis for preliminary work (Mullins *et al.* 1953). In the establishment of a pre-peeling venture, experimental runs should be made, simulating as far as possible the actual equipment, packages, and storage conditions that are contemplated, before the commercial operations are initiated. In general, successive trials should be made in an attempt to determine the minimum strength of solution that will provide the degree of preservation required. If the treatment is too strong, the resulting sulfite flavor may result in customer complaints and undue leakage. Conversely, if the treatment is too mild, preservation is inadequate and costly replacements of product for customers would be required to maintain their good will.

The two formulas given below are to be considered as possible treating solutions for pre-peeled potatoes. They have been found effective in color preservation of peeled potatoes in laboratory demonstrations, but they cannot be considered as recommended treatments for a commercial establishment for reasons stated above. They can be used for preliminary experiments and adjusted as indicated to provide for more or less severe requirements for preservation.

Treatment A.—Dip the peeled potatoes (whole or cut) for 30 seconds in a 1.7 per cent solution of sodium bisulfite (that is, 14.4 lbs. of sodium bisulfite in 100 gal. water), drain, package, and place under refrigeration, avoid freezing temperatures.

Treatment B.—Dip the peeled potatoes (whole or cut) for 30 seconds in a solution of 0.5 per cent sodium bisulfite and 0.5 per cent citric acid monohydrate (that is 4.2 lbs. of sodium bisulfite and 4.2 lbs. of citric acid in 100 gal. of water), drain, package, and place under refrigeration, avoiding freezing temperatures.

To strengthen the treatment, more of the chemicals are used or the dipping time is increased. If the solution is too acid in Treatment B, moisture will come to the surface of the potato and leakage may occur with prolonged storage.[1] This may be corrected by reducing the amount of acid used, which, in turn, would necessitate the addition of more sulfite to achieve an equivalent degree of color preservation.

Determination of Sulfite and Acid in Treating Solution

With use, the treating solution will gradually lose its strength through absorption of the sulfite by the product and by dilution with wash water carried into the tank. Periodic checks should be made during operations and after any substantial shut down so that the strength of solution may be readjusted by addition of reagents. With practice, an analysis for sulfite can be done in a few minutes with apparatus and solutions obtainable from most laboratory supply houses. The following procedures may be used for checking the treating bath.

Method I: Procedure for Sodium Bisulfite.—Transfer 10 ml. of the treating solution by means of a 10-ml. pipette to a 250-ml. Erlenmeyer

[1] With more acid, an increased amount of sulfur dioxide escapes from the solution and better ventilation of the processing area may be required. The frequency of testing will vary with the character of the operations. For this reason, it would probably be advisable to consult with a professional chemist in order to establish procedures for controlling the solution strength. When the technical operations are established and a suitable strength of solution determined for normal operations, the testing and addition of reagents can be conducted with little training by a foreman or someone on the plant operating staff.

flask containing about 50 ml. of distilled water. Slowly add 0.1 N iodine[2] solution from a 50-ml. glass-stoppered burette, with agitation of the flask, until a faint, permanent yellow color appears. Multiply the burette reading by 0.057[3] to obtain the percentage strength of sodium bisulfite solution. For example, if 30.0 ml. of iodine solution were used, $30.0 \times 0.057 = 1.7$ per cent sodium bisulfite, which is the solution strength.[4] (Table 58 lists some of the related values.) It should be noted that for routine opera-

TABLE 58

DETERMINATION OF SODIUM BISULFITE FROM VOLUME OF IODINE SOLUTION USED. METHOD I

Iodine, 0.1 N for 10 Ml. Bisulfite	Concentration of Bisulfite
Ml.	Per cent
5	0.28
10	0.57
15	0.85
20	1.14
25	1.42
30	1.71
35	1.99

tions the amount of iodine solution required can be used directly as an indication of the solution strength as long as the iodine strength and the volume of the sulfite solution analyzed are not changed. If other sulfur-dioxide-containing reagents (such as sodium sulfite, sodium metabisulfite, sulfur dioxide, or mixtures) are used, the factors for concentration of the chemical would require modification. However, the titration values reflect the sulfur dioxide content which is the active ingredient and therefore are a direct measure of the relative strength of solution.

Method II: Procedure for Sodium Bisulfite.—Fill a 50-ml. burette with the treatment solution to be analyzed and add it slowly to 50 ml. of 0.1 N iodine (measured by pipette) and about 25 ml. distilled water in a 250-ml. Erlenmeyer flask. Agitate the flask during the titration and stop when the yellow-brown color disappears. Divide 26 by the number of milliliters of solution.[5] For example, if 15.3 ml. of the sample are used to reduce the 50 ml. of 0.1 N iodine, then $26/15.3 = 1.7$ per cent, which

[2] The standard iodine solution should be kept in a dark bottle and stored in the dark.

[3] For practical use, factors have been rounded off to two significant figures.

[4] The equation for the main reactions: $NaHSO_3 + I_2 + H_2O = NaHSO_4 + 2HI$. Hence, 100 ml. 0.1 N iodine will oxidize 0.5203 gm. $NaHSO_3$ when conversion is complete. However, since the method outlined sacrifices some accuracy for speed and simplicity, the constant of the equation ($f = 0.057$) and the values in Table 58 have been modified to reflect the average sulfite recovery (92 per cent) based on a series of experimental results. The lower, but fairly constant, results are due in part to a secondary reaction: $SO_2 + 4HI = 2H_2O + 2I_2 + S$.

[5] One hundred milliliters of 0.1 N KI_3 solution will oxidize 0.5203 gm. of $NaHSO_3$.

is the strength of the sodium bisulfite solution. Table 59 lists some of the related values.

TABLE 59

DETERMINATION OF SODIUM BISULFITE FROM VOLUME OF SAMPLE EQUIVALENT TO 50 ML. OF 0.1 N IODINE. METHOD II

Sample Used	Sodium Bisulfite
Ml.	Per cent
5	5.20
10	2.60
15	1.73
20	1.30
25	1.04
30	0.87
35	0.74

Method II is a little less rapid than Method I. If there is suspended matter in the solution it may be necessary to filter (a cotton and gauze milk-filter disk will serve) to avoid clogging the burette. However, this method is more reproducible than Method I and the values are equivalent to theoretical. The added accuracy, in most cases, is not required.

Method II can be easily adapted to establish the purity of sodium bisulfite as purchased, by making up a fresh solution of known percentage by careful weighing and determining its strength. This solution should be analyzed without delay, since a slow decomposition of sulfite may take place at room temperature.

Method III: Procedure for Sodium Bisulfite and Citric Acid in the Same Solution.—Where sodium bisulfite and citric acid are both used in the treating solution, two titrations are made and the strength of each component is calculated. The total acidity of the solution is measured first and then the bisulfite strength is determined in the same sample. The amount of citric acid is determined by subtracting from the total acidity the amount of acid represented by the sodium bisulfite.

Total Acid.—Transfer 25.0 ml. of the treating solution to a 250-ml. Erlenmeyer flask and add 4 to 5 drops of phenolphthalein indicator. While agitating the flask, slowly add 0.1 N sodium hydroxide solution from a 50-ml. burette[6] until the first definite pink color results.[7] Record the amount of alkali used and retain the flask and contents for the bisulfite determination.

[6] A burette with pinchcock attachment is advisable for titrating sodium hydroxide, because the alkali will frequently cause a glass stopcock to stick.

[7] The alkali titration of sodium bisulfite with phenolphthalein as an indicator does not give a sharp endpoint. As an aid in identification of the pink color, one may run a blank consisting of about 50 ml. of water, 4 to 5 drops of phenolphthalein, and one drop of the standard 0.1 N alkali.

Sodium Bisulfite.—To the sample slowly add 0.1 *N* iodine solution from a 50-ml. burette, with constant agitation of the flask until a faint permanent yellow color results.[8] The burette reading is multiplied by 0.023 to obtain the percentage of sodium bisulfite (92 per cent recovery is assumed). The citric acid is calculated then by subtracting half the volume of the iodine solution used (burette reading) from the amount of sodium hydroxide required and multiplying by 0.030. Thus: (ml. NaOH—ml. $KI_3/2$) 0.030 = per cent citric acid, monohydrate. For example, if a solution requires 27.47 ml. of 0.1 *N* alkali and 22.1 ml. of 0.1 *N* iodine solution, then $(27.47 - 22.1/2)\ 0.030 = 0.5$ per cent citric acid, monohydrate, and $22.1 \times 0.023 = 0.5$ per cent sodium bisulfite.

As with Method I for determination for sulfite solution strength, the calculations presented here represent a 92 per cent recovery of the components. This figure is based on an experimental study of solutions containing from 0.1 to 1.0 per cent of both sodium bisulfite and citric acid, monohydrate, reagent grade. It was found that calculated acidity ranged from 91.6 to 95.1 (mean 93.3)[9] per cent, and sodium bisulfite ranged from 89.3 to 92.8 (mean 91.5) per cent of theoretical recovery. A range of this magnitude is of little significance in the control of solution strength for plant operations.

Solutions of Sodium Bisulfite and Other Acids

In some cases edible acids other than citric may be desirable and modifications must be made in the method of measuring acid strength. Carbonic acid is sometimes used and is applied by bubbling carbon dioxide gas into the tank from a cylinder. However, the loss of this gas to the atmosphere may be excessive unless the means of addition is carefully worked out. It may be difficult to attain and maintain a concentration of carbonic acid suitable to the conditions required. The determination of carbon dioxide can be done by adding an excess of 0.1 *N* barium hydroxide and back titrating the excess with 0.1 *N* hydrochloric acid with phenolphthalein as an indicator.

The barium solution will absorb carbon dioxide from the atmosphere during preparation unless air is excluded. The burette assembly should be protected with a soda-lime tube. This should, in turn, be blanked off from the air with a rubber stopper when not in continuous use. The barium hydroxide should be checked occasionally with standard hydrochloric acid.

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[8] The pink color fades as iodine is added.

[9] The neutralization of sodium bisulfite with alkali is incomplete unless neutral hydrogen peroxide is added.

When phosphoric acid is used to acidify the bisulfite solution the direct alkali titration of all three hydrogens is not complete. However, an approximation may be accomplished by using two indicators. The first titration is made to the methyl orange end point with 0.1 *N* alkali. Calcium chloride is then added and the solution chilled to below 68°F. to precipitate calcium phosphate. The titration is then continued to the phenolphthalein end point with all three hydrogens neutralized. More accurate methods for phosphoric acid analysis are considerably slower.

REFRIGERATION

Low temperature is used for retarding discoloration and bacterial spoilage of the peeled potatoes. Since freezing is not feasible for pre-peeling operations, storage temperatures between freezing and 40°F. are recommended. Even in this temperature range the product is perishable —perhaps more perishable than pasteurized milk. However, with proper treatment and reasonably sanitary precautions to prevent undue contamination at the time of processing, peeled potatoes may be held for 5 to 7 days at such temperatures without spoiling.

It is important that the product be cooled before packaging because the removal of heat from a stack of packaged potatoes is very slow (Ceponis and Friedman 1957). Observations have been reported of pallet loads of closely packed pre-peeled potatoes holding a center temperature of 70°F. for 15 hours, in a storage room of 40°F. with air circulation (Harrington *et al.* 1956). On the other hand, French-fry cuts were cooled from 80 to 40°F. in less than four minutes by immersion in a treating solution that had been refrigerated to 34°F.

It is not possible to cool whole peeled potatoes so rapidly. However, much heat can be removed from such potatoes by using a refrigerated treating solution. With whole potatoes, adequate circulation around each package in subsequent storage should be provided until the product temperature has been reduced to below 40°F.

Pre-peeled potatoes should always be pre-cooled below 40°F. before delivery. With well insulated or refrigerated delivery trucks the product can thus be delivered to the customer in a condition that will assure a satisfactory product.

Temperature control is also important after the product reaches the hands of the customer. Adequate instruction should be given to the customer so that satisfaction will result in the use of pre-peeled potatoes. Except for cases of very rapid use, the package should not be placed outside of the refrigerator, e.g., at a convenient but hot location near the French fryer. If refrigerator space is not adequate the customer should have smaller and more frequent deliveries to assure satisfaction.

Courtesy of Granny Goose Pre-Pared Potato Co.

Fig. 103. Packaging Stand for French-Fry Cuts

Partially stacked pallet of 30-lb. bags of potatoes in foreground.

It is important that refrigeration facilities in the processing plant be adequate for the heat load with some provision for expansion (Harrington *et al.* 1956). A common error has been observed where refrigeration capacity of a pre-peeling establishment did not even approach the theoretical minimum level necessary to remove the sensible heat from the quantity of potatoes being placed in the cold room. Spoilage complaints were inevitable and frequent. Proper engineering in the redesign of facilities for this firm required a several-fold increase in refrigeration capacity.

When refrigeration is adequate, less severe treatment to prevent discoloration is required.

PACKAGING

In a U. S. Department of Agriculture survey (Garrott 1954 and 1955) of the commercial potato peeling industry it was found that twelve different sizes of packages were used ranging from a 12-ounce retail to a 60-lb. institutional pack. A 30-lb. or slightly smaller pack was most generally

used for institutional trade. Bag type packages are most generally used but corrugated, waxed lined cartons have been used in some cases. Bags are usually of two ply construction consisting of an outer Kraft paper bag with a polyethylene, high-wet-strength Kraft, or wax paper inner liner. In the early phases of development of the industry, wooden apple boxes lined with waxed paper were used. The re-use of such boxes posed a serious problem in sanitation.

In selecting a suitable container for distributing pre-peeled potatoes a decision must be made between perforated and non-perforated bags. The packaging of French-fry cuts in one pre-peeling plant is shown in Fig. 103. The non-perforated package provides better protection for the product, but if leakage is severe, the presence of accumulated liquid is very disagreeable to customers. Regardless of the type of bag selected, it is desirable to exercise all precautions, such as raw material selection and modification of preservation treatment, to reduce leakage to a minimum.

RELATED PRODUCTS

Par-fried Potatoes

An important product of a number of pre-peeling plants is the par-fried potato. Potatoes are cut into French-fry strips, partially cooked in deep fat, cooled, packaged, and delivered to the restaurant. For serving, these potatoes need only two or three minutes cooking in deep fat. Such a product need not be treated with sulfite because the cooking inactivates the enzyme system responsible for discoloration. It can be held under adequate refrigeration for several days.

Par-fried potatoes have an added convenience factor when compared with uncooked pre-peeled potatoes. They can be prepared in a minimum of time and thus can be more easily served on a short order basis by the restaurant. Many restaurants par-fry potatoes and hold them for frying-off during rush hours. Because of the more adequate cooking facilities in a specialized pre-peeling establishment, the pre-peeler can achieve economies of specialization and devote more attention to cooking quality of raw material.

Hash-browned Potatoes

Hash-browned potatoes are prepared by steaming or boiling whole potatoes, allowing them to cool, and cutting or grating into strips about one-eighth inch square cross sections (Harrington *et al.* 1956). Rapid cooling and adequate refrigeration are also required for this product.

A cake of this material is prepared for serving by heating on a grill or in a frying pan until the surfaces are browned.

Broken pieces and slivers from the French-fry line can be used in making stock for hash-browned potatoes. However, cutting before cooking releases easily solubilized starch which must be removed from these pieces by washing. Washing these small pieces tends to leach the compounds that impart the brown color to the surface of the cake during cooking and an undesirably light color in the cooked product results from the use of this recovered material. It is possible to restore the color components by dipping them in a 3 to 5 per cent solution of glucose, which is a major ingredient of the color reaction. On the other hand, a better solution is the combination of one part of the recovered material with two parts of potato shreds made from cooked whole potatoes that have been cooled before shredding. These can be made from potatoes too small for efficient cutting into French-fry strips.

This product is more susceptible to spoilage than is the uncooked pre-peeled potato. This is probably due to the greater microbial contamination that occurs in the shredding and mixing of the product. Cooked potato tissue is also more susceptible to spoilage than raw potatoes. Stock for hash-browned potatoes need not be sulfited as the cooking destroys the color producing enzymes.

Blanched Potatoes

In several instances peeled and cut potatoes have been blanched in steam to destroy enzymes. When cooled and packaged, the product could be French fried by customers with much the same advantages afforded by sulfited pre-peeled potatoes. This product is very susceptible to bacterial spoilage.

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Irvin C. Feustel

Miscellaneous Products from Potatoes

INTRODUCTION

Potatoes have served as a raw material in many different industrial as well as food products. Most of these have been covered in preceding chapters. In this chapter the discussion includes the use of potatoes for production of alcohol and other fermentation products and a number of specialty food items not included elsewhere in the book. Among the latter are a number of new or experimental products that have been developed through research.

INDUSTRIAL PRODUCTS

Potatoes as a Source of Alcohol

Potatoes are rich in starch which can readily be converted into the fermentable sugars maltose and dextrose for production of alcohol and other chemicals. The potatoes may be ground to a slurry in a hammer mill, then cooked and treated with malt or other preparations containing starch-splitting enzymes. Procedures for yeast fermentation and recovery of alcohol are generally similar to those used with other starchy raw materials.

At one time potatoes were used extensively for alcohol production in Germany and special types of potatoes containing 18 to 20 per cent starch were developed for this purpose. The German government controlled the manufacture and distribution of the alcohol. Utilization of potatoes by fermentation has never achieved any degree of commercial importance in the United States except for brief periods during and immediately following World War II.

A small experimental alcohol plant was owned and operated by the State of Idaho at Idaho Falls before the war in an effort to solve the problem of disposing of cull and surplus potatoes. This did not prove to be a practicable venture. Later, in 1944, the War Food Administration conducted more extensive commercial trials of processing surplus potatoes into alcohol as an emergency measure to aid in the war effort. The

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potatoes were dehydrated in inactive beet-sugar plants and the dried product was shipped to alcohol fermentation plants for conversion. Only small quantities of alcohol were produced under this plan because of technical difficulties in handling and processing the potatoes. The machinery and equipment of the beet-sugar factory were not designed for dehydration of potatoes and lack of uniformity in drying caused subsequent difficulties in handling. Alcohol plants were designed to handle grain and the use of the potatoes frequently necessitated much hand labor. It is noteworthy, however, that the dried potato was approximately equal to corn in alcohol yield. According to Jacobs (1950) "dehydration costs approximated $5 per ton of raw potatoes processed, to which freight and potato costs had to be added; consequently, the dehydrated material costs more than corn. About seven tons of raw potatoes were required to produce one ton of dehydrated potato."

Some alcohol plants installed facilities specifically for handling raw potatoes in dealing with the surplus potato crop of 1946. At this time large quantities of potatoes were obtainable from the Government at low cost and extensive use was made of potatoes for manufacture of both industrial and beverage alcohol. Treadway and Cordon (1950–51) reported that 29 million bushels of potatoes were used by alcohol distilleries in 1946. Some of the alcohol appeared in blended whiskies and liqueurs. In 1947, 13.3 per cent of the alcohol produced in the United States was reported to have come from potatoes as compared to 16.5 per cent from grain. Molasses and petroleum served as raw materials for most of the alcohol production.

Efforts were made, without much success, to popularize blended whiskey containing potato alcohol during and for a short time after World War II. The law required that the source of the alcohol be shown on the bottle label. This had an adverse effect on the use of potato alcohol because of consumer prejudice and the idea that this was an inferior war substitute. Production of beverage alcohol from grain was banned during the period of hostilities owing to the urgent need for industrial alcohol to meet the war effort. When grain alcohol again became available for beverage use after the war little or no market remained for the potato alcohol. However, Europeans have long used potato alcohol in vodka and other liquors.

Butyl alcohol, used in the formulation of lacquers and in synthesis of organic chemicals was also produced from potatoes. Eighteen per cent of the 35 million bushels of surplus potatoes from the 1947 crop went into ethyl and butyl alcohols. In 1948, 34 per cent of the 133 million bushels of potatoes purchased by the Government were used to produce these

two alcohols. Thereafter, few if any potatoes went into alcohol manufacture.

Except for special applications potatoes are not considered as an economical raw material for use in fermentation. Since potatoes consist of about 80 per cent water they are bulky and costly to transport and handle. Low grade potatoes, such as would be utilized for this purpose are also subject to spoilage unless dehydrated. Transportation costs can be minimized by locating the processing plant in a potato producing area but even then the potatoes cannot ordinarily compete with blackstrap molasses. Synthetic processes for alcohol production using petroleum as a raw material also have significant economic advantages over potatoes. Nevertheless, research workers are on the alert for nutrient requirements in fermentations for which potatoes may possess some natural superiority that will enable them to command a higher price than is warranted by their carbohydrate content alone.

Microbiological Culture Media

The amino acids and minerals together with the carbohydrates contained in potatoes furnish an excellent medium for the growth of micro-organisms. For this reason, potato broth, the liquid obtained from boiled potatoes, has long been used by microbiologists as an ingredient of culture media for stimulating growth of various bacteria, yeasts and molds. Such media are useful for different purposes such as identifying different species of micro-organisms, for making counts to determine numbers of micro-organisms in samples of food products, and for the maintenance of culture collections of certain industrially important micro-organisms, particularly molds (Haynes *et al.* 1955).

The potato broth or infusion which is to be used in a culture medium may be prepared from fresh potato. One method is to boil peeled and diced potato in water until thoroughly cooked. The mixture is filtered through cheesecloth. Agar and dextrose are then added in the proper proportions and the mixture sterilized. Another method of preparing the potato infusion is to hold the raw diced potato in water at 140°F. overnight instead of cooking.

Microbiological culture media in dehydrated form containing potato are produced for commercial sale (Anon. 1955). A typical product is known as "Potato Dextrose Agar." It contains potato infusion, 200 parts; dextrose, 20 parts; and agar, 15 parts by weight. Such a preparation is recommended for making counts of yeasts and molds in dairy products and in frozen dessert ingredients. Another product, "Potato Infusion Agar," contains beef extract, proteose peptone, salt, dextrose and agar in addition to the potato infusion.

Potato water has been used as a nutritional supplement in producing penicillin in Germany. According to a report by Kleiderer *et al.* (1945) this was the best supplementary substance found for this purpose and it retained its effectiveness even after long standing.

Lactic Acid Fermentation

Production of lactic acid as a fermentation product of potatoes was investigated by Cordon *et al.* (1950) in a search for industrial products that could be made from cull and surplus potatoes. Potato starch had served previously as a raw material for manufacture of lactic acid in Germany. Either malt or sulfuric acid was used for conversion of the starch to sugar in preparation for fermentation.

In the experimental work reported above, whole washed potatoes were ground in a hammer mill, water was then added to the raw mash before cooking to reduce the consistency and to prevent crystallization of calcium lactate formed during fermentation. Cooking and sterilization were accomplished by heating a short time at 212°F. followed by autoclaving at 257° to 275°F. Fungal amylases (*Aspergillus niger*) were used to convert the starch to sugars, and several strains of lactobacilli were evaluated for their ability to produce lactic acid in the potato medium. Yields of lactic acid of 80 to 90 per cent (based on original carbohydrate) were obtained in the fermentation mixture. An average of 85.5 per cent of this was recovered.

FOOD PRODUCTS

Canned Potato Salad

German Style.—Two types of canned potato salad are produced. One is known as German style and the other as American or mayonnaise style potato salad. The German style, which is produced in the largest volume, is commonly served as a hot dish, but may also be used as a cold salad. It is a specialty product consisting of potatoes, bacon, onions and parsley in a sauce formulated from bacon fat, vinegar, water, seasoning and thickening agents. The formula on page 440, which is sufficient to yield 70 to 75 No. 2 (307 x 409) cans of product, has been suggested by the Continental Can Co., Inc., Chicago, Illinois.

Although the above formula has been found to give a satisfactory product and to provide a good basis for the development of individual formulations, each canner usually prefers to develop a product with some distinctive flavor or consistency characteristics. Amounts and type of seasoning and amount of vinegar can be varied to vary the flavor although sufficient vinegar must be used in order to maintain an equalized pH of

Solid Ingredients		Sauce	
Potatoes (prepared)	70.0 lbs.	Flour or starch	0.5 lb.[1]
Bacon (fried crisp)	2.5 lbs.	Bacon fat	2.5 lbs.
Onions	1.0 lb.	Sugar	5.0 lbs.
Parsley (fresh)	6.0 oz.	Salt	1.5 lbs.
		Pepper	0.66 oz.
		Vinegar (100 grain)	3.2 lbs.
		Water to make	5.0 gal.

[1] If flour is used, up to 2.5 lbs. may be desirable.

4.5 or less for sterilization purposes. Different types and amounts of thickening agents may be used in the sauce and the water content varied to alter the consistency as may be desired. A flow sheet for the preparation of this product is shown in Fig. 104.

Freshly harvested or "new" potatoes are considered the most desirable for making salad because these have the lowest peeling losses and give the best texture in the finished product. Mealy potatoes are not well suited since these are inclined to slough and break up during cooking. Potatoes retain good quality for canning for several months if stored under conditions generally recommended for processing use.

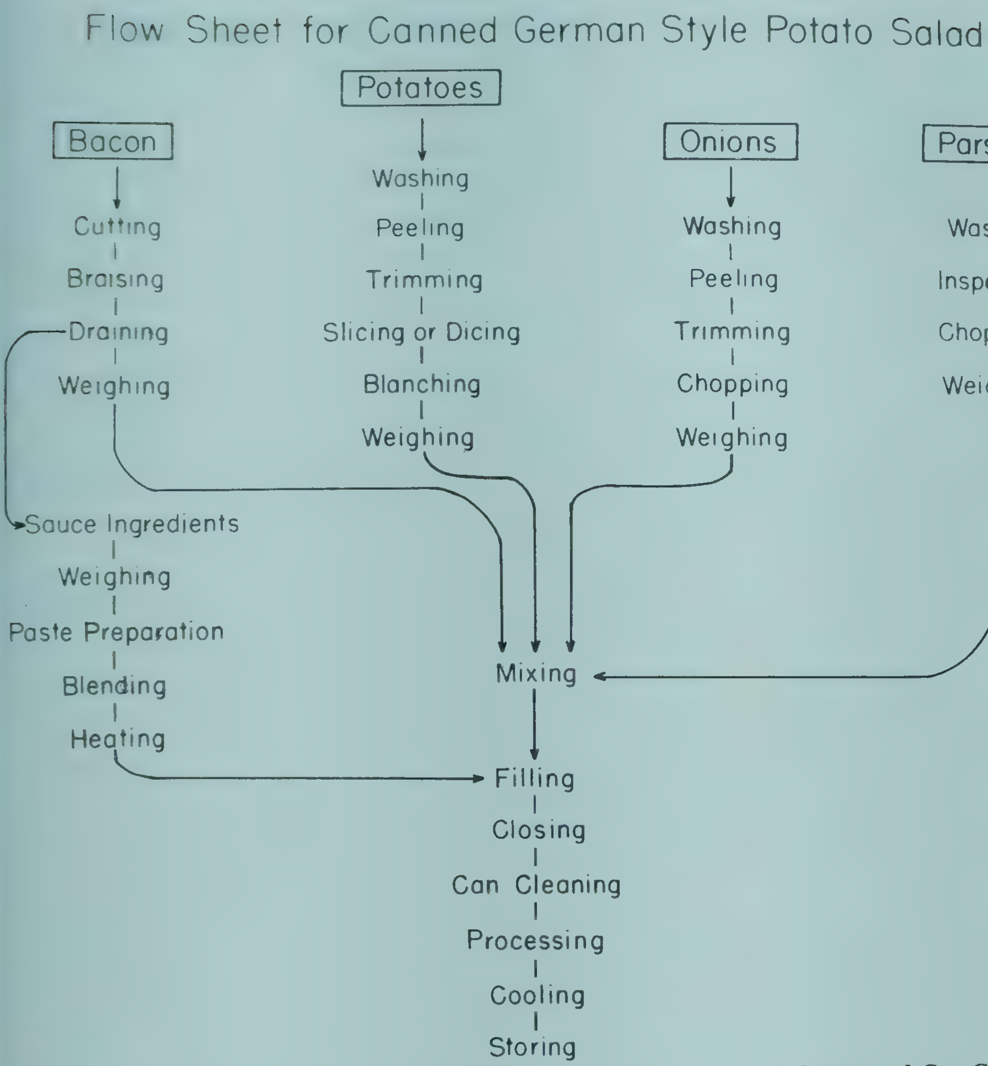
Onions should be selected on the basis of pungency, appearance and freedom from defects. Red, White or Yellow Globe or Ebenezer varieties are used for this purpose. The onions should be sun-cured after harvest and placed in a dry and well ventilated storage held at temperatures between 36° and 40°F. Dehydrated onions may be used in place of fresh onions provided they are rehydrated properly before use.

Properly cured smoked bacon is preferred. It is desirable to have approximately 60 per cent fat and 40 per cent lean.

The vinegar is usually a 100-grain distilled product. Proper allowance in formulation of the salad must be used if a vinegar of different grain strength is used since the acidity must be carefully controlled.

In preparation for canning the potatoes are peeled, trimmed, inspected and washed in cold water. The potatoes are then sliced or diced to the desired size and blanched in water at 200°F. for 2 to 4 minutes to prevent enzymatic darkening during mixing and filling operations and to precook partially the potatoes. If there is a delay between peeling and blanching the potatoes should be immersed in a salt brine in order to prevent darkening.

Onions are peeled, trimmed and diced into approximately one-fourth inch cubes or cut by grinding through a $^3/_8$-in. screen. The bacon is fried until crisp either in the form of slices or small pieces. The fat is drained



Courtesy of Continental Can Co., Inc.

FIG. 104. FLOW SHEET FOR PREPARING CANNED GERMAN-STYLE POTATO SALAD

off after frying and used in making the sauce. Parsley is thoroughly cleaned. Yellow leaves, stems and foreign material are removed and the tops are chopped into small pieces.

Mixing is usually a batch operation and is frequently done by hand. Various types of equipment are used including stainless steel tables and hand paddles, kettles with mixing blades, or revolving reels or drums fitted with baffles. Precautions must be taken to insure a uniform mixture and to avoid breaking the potatoes. The potatoes are mixed with the bacon, onions and parsley as soon as possible after blanching.

The sauce is prepared by adding the flour or starch to the bacon fat in a steam-jacketed kettle. The mixture is heated until a smooth paste is obtained. The vinegar, water, sugar, salt and pepper are mixed

thoroughly and added to the sauce paste. The sauce is heated at a minimum temperature of 200°F. with constant mixing, until the desired consistency is attained. Prolonged heating must be avoided, however, to prevent loss of acetic acid from the vinegar.

The mixed solid ingredients and the sauce are best filled separately with a portion of the sauce placed in the cans before the solid ingredients are added in order to avoid entrapping air. The remainder of the sauce is

Table 60

PROCESSING SCHEDULE[1]

Can Name	Dimension	Approximate Net Weight	Initial Temp., °F.[2]	Minutes at 212°F.	Minutes at 240°F.[3]
No. 1 Picnic	211 x 400	11 oz.	100	60	70
			120	55	65
			140	50	60
			160	45	55
No. 300	300 x 407	1 lb.	100	70	80
			120	65	75
			140	60	70
			160	55	65
No. 303	303 x 406	1 lb. 2 oz.	100	75	90
			120	70	85
			140	65	80
			160	60	75
No. 2	307 x 409	1 lb. 5 oz.	100	85	100
			120	80	95
			140	70	90
			160	65	85
No. $2^1/_2$	401 x 411	1 lb. 15.5 oz.	100	100	115
			120	90	110
			140	80	105
			160	70	100
No. 10	603 x 700	7 lbs.	100	205	240
			120	185	225
			140	160	210
			160	140	190

[1] Suggested by the Continental Can Company, Inc., Chicago, Illinois.
[2] Initial temperature designates the average temperature of the can contents at the time the steam is turned on for the process, or the cans are placed in the boiling water. It is to be regarded as a prerequisite of the process suggested.
[3] Processing schedules at 212° apply if the equilibrium pH (attained after processing) is below 4.5. If the equilibrium pH is above 4.5 the schedules at 240°F. are suggested.

then filled with a syruper. However, some packers prefer to mix the sauce and potatoes before filling since this gives a more uniform mixture. Filled cans or jars should be closed at a minimum average temperature of 160°F. to obtain adequate vacuum with atmospheric closure. If the closing temperature is below 160°F. it is advisable to use steam for a vacuum closure.

There should be as little delay as possible between closing and heat processing. Processing schedules for different can sizes are shown in Table 60.

Processing may be done in boiling water if the water is boiling at the

time the process is started and maintained at the boiling point for the recommended time. Sterility will not be achieved under these conditions if the equilibrium pH after processing is 4.5 or above. This means that the sauce should have a pH of 4.1 at the time of processing. This degree of acidity will ordinarily be achieved if the product is properly formulated with respect to strength and amount of vinegar. If the equilibrium pH is in the range of 4.5 to 4.9 processng at 240°F. is suggested.

Cans should be water-cooled immediately after processing. Storage temperatures between 50° and 60°F. are recommended for increased shelf life of product.

American Style Potato Salad.—Canned American or mayonnaise style potato salad comprises a mixture of diced potatoes, cooked or stabilized salad dressing, vinegar, onions, red bell peppers or pimientos, spices and salt. Formulations may include other ingredients, such as celery, and are varied to suit preferences of individual packers as in the case of the German style product. Typical recipes contain about 60–70 per cent potato and 25–35 per cent salad dressing.

American style potato salad as usually prepared by the housewife cannot be canned successfully because heat sterilization causes the salad dressing to separate and curdle with liberation of free oil. Stabilization of the salad dressing was the greatest problem to overcome in the commercial development of a canned product. Experience has shown that a cooked or "boiled" salad dressing emulsion of relatively low oil content and high acidity (low pH) must be used. It has also been found necessary to use a waxy type of starch as a base for the dressing in order to prevent gelation or solidification of the canned product during storage.

The potatoes are boiled or steamed but are not cooked completely. These may be diced after the partial cooking and subsequent cooling. The potatoes may also be diced before cooking. Cooking the diced potatoes in water acidified with vinegar has been found to toughen the surfaces, thereby minimizing breakdown during processing, as well as an aid to lowering the pH of the product. The partially cooked potato is mixed with salad dressing (previously combined with the required amount of vinegar) along with onions, pimientos, spices, etc. If dehydrated vegetables such as onion flakes are used these must be properly rehydrated before incorporation in the salad mixture. Mixing with the salad dressing must be thorough without breaking up the potatoes. Cans or jars are filled by hand or by semi-automatic fillers.

Steam flow closure or vacuum sealing is strongly recommended to prevent oxidation of product during storage and to prolong shelf life. The closed cans are processed in boiling water or steam for sterilization. The pH of the product must be carefully controlled so as to fall within

the range of about 4.2 to 4.4. The cans should be thoroughly cooled following processing and stored in a cool dry warehouse.

American style potato salad is also marketed as a fresh item in refrigerated food cabinets. Formulas used are similar to those used for home preparation. Potatoes suitable for salad manufacture are peeled, diced to $^1/_2$-in. cubes and cooked with steam. The potatoes may also be cooked whole and then diced but this procedure necessitates a period of cooling before dicing. Mayonnaise, boiled egg, pimento, celery, onion, parsley, salt and spice, or other ingredients as may be desired, are mixed with the cooked diced potato, usually in a batch operation, with the aid of mechanical mixtures. Sodium benzoate is added as a preservative before packaging.

Canned Corned Beef Hash and Beef Stew

Dehydrated diced potatoes are commonly used for canned meat products. These are reconstituted by simmering in water about 15 to 20 minutes. If raw potatoes are used they are chopped or diced prior to adding to the mixture. They should be firm and not become mushy in the finished product. Ingredients other than meat and potatoes in corned beef hash include onions, beef fat, sugar, salt and pepper, and sodium nitrite. The potatoes comprise about 45 per cent of the weight of the product in a typical formula. Standards of identity require that the finished product contain not less than 35 per cent of cooked and trimmed beef. The raw meat is given a curing treatment in a salt water-sodium nitrite mixture and may also be parboiled before mixing with the other ingredients. Canned beef stew usually contains carrots, tomato purée, and cereal flour in addition to beef, potatoes and seasoning.

Potato Soup

Potatoes used in canned soups are usually prepared in dice form. Finely chopped onions or onion powder, milk, salt, pepper, butter, vegetable oil and flour are generally used as ingredients in the soup. Formulations vary according to preferences of different processors and demands of the trade. No Federal definitions or standards of identity have been issued but the product is subject to the general regulations of the Federal Food, Drug and Cosmetic Act of 1938 in addition to state and local regulations where packed.

Canned French-Fried or Shoestring Potatoes

French-fried or shoestring potatoes prepared for canning are fried in oil until the moisture is reduced to about 5 to 8 per cent. Ordinarily, French-fried potatoes contain a much higher moisture content. A low

moisture is attained in the case of the shoestring potatoes without the product becoming too dark in color because the pieces are small. Frying time, 4 to 5 minutes at 350° to 375°F., is about the same as that required for ordinary French-fried potatoes. Potato chip manufacturing equipment is generally used in producing this product, and processing procedures are similar to those used for chips.

After frying, the potatoes are drained of excess fat by passing over a mesh conveyor. A salt sprinkler is used to salt the product. Antioxidants may be added with the salt to increase shelf life. Antioxidant is not required if the product is gas or vacuum packed.

Shoestring potatoes present a problem in packing the correct weight in the can without the use of excessive hand labor. Special filling equipment for orienting the pieces has been devised for overcoming this problem. The product possesses a long shelf life which is an important factor in the popularity which it enjoys.

Dehydrated Mashed Potatoes

Three different types of dehydrated mashed potatoes are in commercial production. Two of these, potato "granules" and potato "flakes" are described in Chapters 12 and 13, respectively. The third type, known as "Minute" mashed potato and sometimes referred to as a shredded material, is prepared by cooking and mashing fresh potatoes as in the case of the above-mentioned products. Non-fat dry milk solids and an emulsifier are incorporated with the freshly mashed potato. It is then extruded through specially designed equipment in a form resembling sphaghetti. This material is automatically spread out in a thin layer on a mesh belt and dehydrated in a continuous hot air drier. The dried product is removed from the belt, given a final inspection and packaged with four servings to a package. It is prepared for serving by mixing with boiling water, adding butter and seasoning to taste, and whipping briefly with a fork. Milk may also be added if desired.

Potato Pancakes and Pancake Mixes

Potato pancakes are said to have originated in Bavaria, Germany. Traditionally, this dish has been prepared from grated raw potato which is mixed with eggs, flour, onion, baking powder, salt, and bacon fat. The batter is placed in hot fat and fried until golden brown. A dehydrated potato pancake mix was reported to have been developed by Pfanni-Werk in Munich, Germany, during World War II. It was introduced to the German market in 1949. When mixed with water, this product yields the batter for both potato dumplings and potato pancakes and can be used in a variety of dishes. Today, a variety of packaged dry potato

pancake mixes are available from commercial manufacturers. These are formulated from dehydrated potato cereal flour or starch, salt, and in some instances onion and dried egg may also be included.

In order to obtain the typical flavor and texture of potato pancakes which are prepared from freshly grated potatoes it is common practice to use at least a portion of raw dehydrated potato in the prepared mix. The raw potato may be dehydrated under vacuum in order to preserve as much of the fresh quality as possible. Special methods are used to prevent darkening of the raw potato during dehydration. This material is coarsely grated so as to confer the desired texture on the finished product. Another portion of the mix is prepared from blanched or cooked potato which is dehydrated in the form of dice and then finely ground. Sufficient potato starch and flour are added to provide the necessary adhesiveness in the pancake. Seasoning is also added. In preparing the product for serving it is necessary only to mix with water to form a batter. Milk and egg may also be incorporated in the batter if desired.

Considerable quantities of potato pancake and potato dumpling mix are produced in Germany and some is exported to the United States. Tray dehydrators used in Germany comprise specially designed drying cabinets. The trays which are relatively large are moved from one drying position to another as drying progresses. (See Fig. 105.) Continuous belt-type driers have come into use in recent years. Such units may consist of two or more belts which convey the grated or diced potato from one stage of dehydration to another. After completing passage on one belt the product drops to the next belt. The dried material is then ground for incorporation into the pancake and dumpling mix.

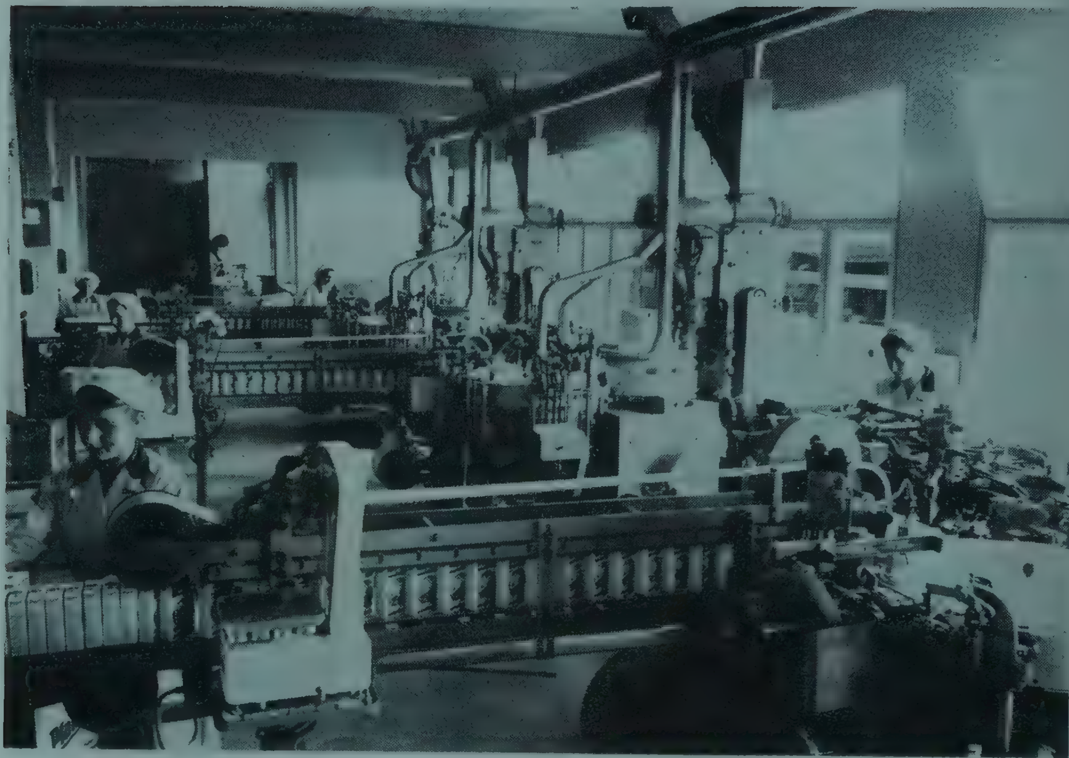
Another type of potato pancake mix is packed fresh in sealed tins. Potatoes are peeled by abrasion and ground in meat grinding type of equipment and passed through a $^1/_4$-in. screen. A small quantity of sulfite is added to the ground material for preservation of color. Flour, fresh eggs and seasoning are also added. The mixture is packed in tin cans and heat sterilized. This product assumes a solid roll or loaf form corresponding to the contour of the can as the result of a special formulation and processing procedure. The product may readily be removed from the can in a solid piece after opening both ends of the can. It requires only slicing in preparation for frying and serving. The pancakes may be fried either in a hot pan or in deep fat for 2 to 3 minutes.

Potato Chip Bars

The Quartermaster Corps of the U. S. Army has been unable to supply potato chips in their usual popular form as a ration item because of their excessive space requirement in packaging and the lack of storage stability.

Courtesy of Pfanni-Werk, Munich, Germany

FIG. 105. A SERIES OF TRAY DEHYDRATORS USED IN GERMANY FOR MANUFACTURE OF POTATO PANCAKE AND DUMPLING MIX



Courtesy of Pfanni-Werk, Munich, Germany

FIG. 106. FILLING AND PACKAGING LINES FOR POTATO PANCAKE AND DUMPLING MIX IN A GERMAN PLANT

Treadway *et al.* (1958) developed a potato chip bar suitable for military use by crushing potato chips and compressing them to about one-twentieth of their original package volume (see also p. 273). The bars are approximately 3 in. long by 1 in. wide and $^5/_8$ in. thick. This product was found to have excellent performance characteristics in terms of the Quartermaster requirements for acceptability, nutritive qualities, storage life and convenience of use. Consumer-type panel evaluation indicated that the bars might also have possibilities as a civilian snack item and that they could serve as a concentrated foodstuff for stockpiling for disaster feeding. Limited experience in semi-commercial production indicated feasibility of full scale manufacture of the new product.

Experimental conditions that were investigated in producing potato chip bars included selection of the proper type of fat for frying the chips, a determination of the range of particle sizes to which the chips should be reduced before pressing, amount of pressure, mode of pressure application and application time in order to obtain the best results.

Chips crushed to $^1/_8$ to $^1/_4$ in. on a side and compressed at 500 to 3,000 lbs. per sq. in. gave self supporting bars in which the characteristic crunchy texture of the original chips was preserved. Breakage of chips

to increasingly smaller particle sizes resulted in a material having the consistency of peanut butter. Too large a particle size resulted in poor binding. Oil losses on pressing were small if the chips were fried in hydrogenated shortening and compressed under optimum conditions. A chilling treatment following pressing was found to be of value in firming the bars for wrapping.

Storage stability of the potato chip bars was investigated under various time and temperature conditions. Chips were fried in hydrogenated vegetable shortening and in a vegetable oil-shortening blend each containing a commercial antioxidant. Three moisture levels, 2, 4, and 6 per cent were used. The bars were formed under pressure at 3,000 lbs. per-sq. in. for 4 seconds, then chilled, wrapped in thin aluminum foil and canned in nitrogen and in air. Storage temperatures were 40°, 70° and 100°F. Taste panel evaluation by trained judges indicated that the canned bars were still palatable after storage for one year at 40° and 70°F. Those stored at 100°F. were definitely lower in degree of acceptability. The nitrogen packs were superior to those containing air which indicates that an inert gas is needed to prevent oxidative deterioration during a long storage period, particularly at high storage temperatures. Bars made from chips fried in the vegetable oil-shortening blend developed an off-flavor in six months. Taste panel scores were generally higher with the low moisture samples.

Military standards require that a product should remain palatable for at least six months during storage at 100°F. Stability requirements of a product intended for civilian use would be less rigorous.

Potato Chip Confections

Experiments in the preparation of various candy coated and flavored potato chip confections were described by Townsley and Dixon (1952). These products were made by dusting or glazing the chips with the desired coating. Candy for glazing was heated to 310° to 338°F. then cooled and powdered. Various candy recipes and flavors such as caramel, molasses, peppermint, lemon, maple, peanut taffy, spice, corn syrup and nut brittle were used. Some of the flavors may be added just before the candy is poured for cooling or after it is powdered. An instantaneous flash heat at 1100° to 1300°F. spreads the powder in an even thin glaze over the chips. Chocolate coated potato chips were prepared by dipping unsalted chips in semi-sweet baker's chocolate at 80° to 85°F.

Potato "Nuts"

Shortly after the close of World War II a snack product was produced commercially in Maine and Idaho by frying dehydrated potato pieces.

Fresh potato pieces, $^3/_8$ x $^3/_8$ x $^1/_4$ in., were dehydrated to about twelve per cent moisture and fried in deep fat to give an end product containing about 20 per cent fat. Generally, the product was rather porous and brittle in structure and its texture was somewhat like parched corn. However, some pieces contained hard, compact areas that were difficult to chew. The problem of hard areas was believed to have discouraged further production of potato nuts.

Courtesy of University of Maine Agricultural Experiment Station

FIG. 107. FRENCH-FRIED POTATO "NUTS" OR DICE

Highlands and Getchell (1956) described French-fried potato dice while Siciliano *et al.* (1956) reported further experiments on this type of product. Raw potatoes were sliced into dice approximately $^3/_8$ x $^3/_8$ x $^1/_4$ in. The dice were blanched in steam for one minute and dried in a forced-draft oven for successive 20-minute periods at 220°, 180° and finally at 145°F. The dried dice were then allowed to equilibrate at room temperature in the open for 20 hours. Following this, they were fried at 325°F. for one minute. The pieces had a tendency to pop like corn when immersed in the hot fat; however, the popping was not sufficient to give the desired crunchy texture.

The best results were obtained when fresh potatoes were sliced into $^1/_4$-in. cubes and fried directly. Larger dice had soft centers after frying.

Smaller dice tended to become excessively brown and hard on frying. Frying time and firmness of centers were also influenced by the total solids content of the potatoes used.

Frying was stopped when the cubes were browned to the desired extent although the oil bath was still frothing due to ebullition of water. Following frying it is believed that the product should be allowed to cool in a dry atmosphere before packaging. If packaged while warm the pieces become tough and chewy probably because of the migration of condensed moisture from the interior of the package to the surface crust. It was also suggested by the investigators to conclude the processing by a step in which the potato "nuts" are heated in an oven. This would drive additional moisture out without the necessity of frying until the pieces are excessively browned.

No work was reported on the effects of varietal differences but good quality "nuts" or dice, as illustrated in Fig. 107, were made from Maine Katahdin and Idaho Russet Burbank potatoes. As in the case of potato chips, potato "nuts" have best color, taste, and texture if made from potatoes of low sugar content.

Potato "Puffs"

Harrington and Griffiths (1950) have developed an oil-free, pillow-shaped potato tidbit which has an attractive crunchy texture and toasted color. It has been tentatively named potato "puffs." A variety of flavors can be easily added and is suitable for out-of-hand eating, as a breakfast food, and for soups, stuffing and casserole dishes. Storage tests have shown that the "puffs" are sufficiently stable for commercial distribution but thus far the product has remained in the experimental stage. These are shown in Fig. 108.

In the preparation of potato puffs, the potatoes are peeled, trimmed and cut into strips $^1/_8$ in. thick, generally $^3/_8$ in. wide, and from $^3/_8$ to 1 in. long. These are blanched in boiling salt water for 15 seconds to 1 minute. The blanched dice or pieces are placed in a special type drier and subjected to a high velocity, vertical, hot air stream. This accomplishes rapid drying of the surface, and at the same time heats the potato sufficiently high so that steam forms internally and expands each piece. The flow of hot air also keeps the dice in constant agitation and in partial suspension, thereby eliminating most of the tendency of pieces to stick together. The moisture of the potato expands to steam more rapidly than it can escape from the surface and puffs the dice to hollow shells. As the moisture level decreases, the puffed pieces become rigid and take on a light brown color. The processing is completed in a drying oven at a reduced temperature to achieve the desired crisp texture. Potato

Fig. 108. Potato "Puffs," a New Kind of Snack Prepared by Rapid Drying and Puffing of Blanched Potato Pieces.

puffs of acceptable quality occupy from 1.6 to 2.0 times the volume of dehydrated potato.

Quality of the product is affected by a number of factors. Size of the potato pieces may be varied but a $^1/_8$-in. thickness appears to be optimum. Thicker pieces tend to produce hard centers; thinner pieces to become fragile and to crack or break later in the process or in subsequent handling. Large pieces tend to puff unevenly.

Velocity of air used for drying varies as the product dries. For the first 3 or 4 minutes, approximately 1800 ft. per min. is required. For the rest

of the initial drying stage, the velocity is gradually reduced to about 500 ft. per min., maintaining sufficient airflow to provide gentle agitation of the product.

Consumer acceptance of the puffs may be enhanced by addition of flavors such as cheese, garlic, onion, sugar, monosodium glutamate and salt. These flavoring agents may be added to the blanching water or be sprinkled in a powdered form over the blanched potatoes.

Sponge-Dehydrated Potato

Harrington *et al.* (1951) described a method of dehydration to produce porous dice that can be converted to mashed potatoes in a few minutes by addition of hot water or other liquid. Cold water may also be used to rehydrate the sponge-dehydrated potatoes but a temperature above 165°F. is required to cause swelling of cells and gelation of starch.

Potatoes of high solids content are washed, peeled, trimmed, cut to half-dice ($^3/_{16}$ x $^3/_{16}$ x $^3/_8$ in.) and cooked about 20 minutes on trays in a steam blancher. The cooked pieces are cooled and placed in a freezing room at —10°F. After hard freezing the material is placed in a room at 40°F. and allowed to thaw slowly over a period of 12 to 16 hours. The trays of thawed product are then placed in a drying chamber maintained at about 130°F. dry-bulb temperature and dried to around eight per cent moisture.

The sponge-dehydrated potato maintains about the same piece dimensions as the cooked pieces before drying. It is bulkier than most dehydrated potato products. It is not advisable to grind the product in the dry state to reduce its volume because cell rupture would be unavoidable. This would release free starch and a pasty product would result on rehydration.

This product is intended primarily for use as mashed potato and in potato cakes but is also considered suitable for use in soups, purées, casserole dishes, hash, chowder, etc.

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M. E. Highlands

Potatoes and Potato Pulp for Livestock Feed

INTRODUCTION

Potatoes are considered primarily a food for human consumption, but, according to Salaman (1949), more potatoes are fed to livestock than are consumed by humans.

In the United States, utilization of raw potatoes for cattle feeding has received increased emphasis during the past 15 to 18 years. This has been encouraged by support prices for potatoes and grains, and by the accumulation of culls when an increasing percentage of sound stock has found its way into processed potato products for human consumption.

It has been estimated, that, of about 300,000,000 bushels of potatoes harvested per year about five per cent went into cattle feeding in the United States (1948–51).

According to Harvey et al. (1951) repeated feeding trials over a period of some six years indicated that potatoes can be successfully fed to cattle when supplemented with other feeding stuffs, including roughage, grains and urea. The quality of finished cattle has been satisfactory and apparently the economics of such feeding is acceptable.

According to Hedlund (1958) in western Europe where land is limited but growing conditions are very favorable for potato production, more total food value can be produced per acre with potatoes than with any other crop. Traditionally in Europe feeding of potatoes and other root crops to livestock has been common practice. In the United States feeding of potatoes to livestock is presently common practice in Oregon, Washington, Idaho, Colorado, Maine, and the Red River Valley of Minnesota and North Dakota. A number of other states use limited quantities for the same purpose. Usually potatoes are fed to cattle in fresh form, whole or chopped.

In some areas of the United States potatoes are dried prior to feeding. For example in California a sizable quantity is sun-dried and fed. Johnson *et al.* (1953) stated that sun-dried potatoes are equivalent to dried molasses beet pulp when fed at 25 to 50 per cent of the concentrate mixture for fattening calves. Approximately three pounds of raw potatoes are required to make one pound of the sun-dried product. Certain areas of

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Courtesy of Kern County Potato Growers Assn.

FIG. 109. CHOPPED CULL POTATOES AFTER APPROXIMATELY 60 HOURS DRYING.

Arrangement in windrows by motor grader exposes the still moist portions to the sun and hot surface of the asphalt airstrip. This windrowing is performed until final dehydration is accomplished.

the country have a climate which makes possible the dehydration of potatoes for feed by alternate freezing and thawing under natural climatic conditions. This system is not feasible when abundant rainfall occurs. While it is true that a considerable amount of nutrient is lost by using this method, it is nevertheless an inexpensive method of handling potatoes to be used in feeding.

Allender (1948) gave an excellent résumé on potatoes for livestock feed, in which he discussed the preservation and storage of potatoes for feeding purposes by methods mentioned above and by ensiling. Johnson *et al.* (1954) reported on potato silage for beef feeding and concluded that potatoes make excellent silage when suitable preservatives and roughages or grains were used as absorptive agents.

The preservation of potatoes according to Pusateri (1958) by natural sun and air drying found acceptance for cattle feeding in California. Potatoes were dried on concrete airstrips. Fig. 109 shows one phase of this operation.

POTATO PULP

Potato pulp from starch plant operations has been used in Europe for feeding cattle and horses according to Ehrenberg and Lachmann (1944) and Eskedal (1938). European practice has generally been to feed wet

pulp whenever possible but dry pulp is also produced and used. In some instances attempts have been made to ensile wet pulp with grass for feeding. This is apparently considered uneconomical at present according to Stein (1958).

TABLE 61

ANALYSES OF STARCH PLANT WASTE PULP (WET BASIS)

Source →	A[1]	B[2]	C[3]
Moisture	91.7	97.5	94.7
Protein	0.7	1.1	0.5
Fat	0.1	0.03	0.02
Fiber	0.9	1.3	0.6
Nitrogen-free extract	6.6	7.2	4.0
Ash	0.3	0.6	0.2

[1] From Henry and Morrison (1950).
[2] From Brautlecht (1940).
[3] From Plummer (1948).

TABLE 62

ANALYSES OF STARCH PLANT WASTE PULP (DRY BASIS)

Source →	A[1]	B[1]	C[2]
Moisture	15.0	0.0	15.0
Protein	24.0	6.8	12.5
Fat	...	...	...
Fiber	10.0	11.0	5.2
Nitrogen-free extract	49.0	79.0	66.0
Ash	2.0	2.5	1.7

[1] From Anon. (1946).
[2] From Snell (1945).

TABLE 63

ANALYSES OF DRIED POTATO PULP FROM TWO TYPES OF PLANTS ON A MOISTURE FREE BASIS

Type of Plant	$Ca(OH)_2$ Added, Per cent	Protein	Fat	Fiber	Ash	Nitrogen-free Extract
Table	None	6.7	0.9	12.0	2.7	77.9
Table	0.3	3.2	0.1	10.8	4.9	81.1
Vat	None	8.3	0.3	9.2	3.6	78.5
Vat	0.3	5.1	0.3	9.0	10.1	75.1

[1] From Highlands (1951).

The utilization of potato starch plant waste pulp for livestock feeding in the United States is comparatively recent. In the United States much starch plant pulp is still wasted, although some is used for feeding as wet and as dried pulp.

During the decade 1948–57 an average of 53,478 tons of white potato starch per year was produced (Mercker 1958). If all available pulp were dried to 10 per cent moisture content, it is possible that 10,160 tons per

year might be produced. This dry weight potential is based on data presented by Eskew *et al.* (1948) that for each 10 tons of starch, 54 tons of 96 per cent water content pulp are produced. This in turn, when dried, amounts to about 1.9 tons of 10 per cent moisture pulp.

It should be noted that the tonnages of pulp produced will vary widely with the methods of starch extraction employed. Modern equipment and methods have resulted in a higher extraction rate with a corresponding decrease in the amount of solids in the waste pulp.

Typical analyses of starch plant waste pulp are shown in Table 61. Other analyses on dried starch plant waste pulp are shown in Table 62.

Analyses of dried potato pulp from two types of plants using limed and untreated pulp are shown in Table 63 based on results obtained by Highlands (1951).

RECOVERY OF POTATO PULP

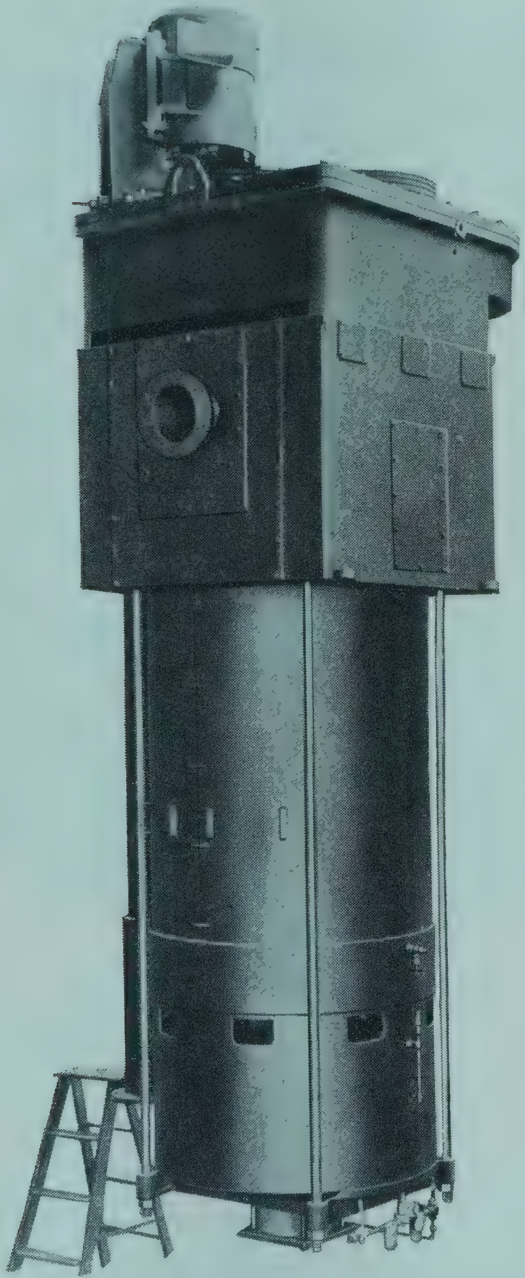
In the recovery of potato starch plant waste pulp some attempt is usually made to lower the moisture content before feeding. This may take the form of allowing large masses of wet pulp to stand in walled enclosures with floors so designed to afford natural drainage. In other instances the pulp may be mechanically pressed. In either type of operation considerable nutrient is lost in the drainage of press water. Since recovery of solids in this effluent is not presently economical the effluent is usually discarded. Most efforts are directed towards the recovery of the insoluble solids fraction present in the pulp.

Wet pulp as it is delivered from the separating screens of a starch plant operation does not lend itself well to dewatering. This is due in part to naturally occurring pectins and other substances present which contribute to its water holding nature and its slippery texture.

Highlands (1951), studying the recovery of insoluble solids from white potato starch plant pulp, noted that five presses were tried, but none was successful in lowering the untreated pulp below approximately 80 per cent moisture.

If pulp was treated with a suitable coagulant and allowed to stand 15 to 30 minutes prior to pressing, results of water removal were greatly improved. The variation in the time interval depends on the condition of the pulp.

Coagulants examined for their effect on pulp to improve water removal included $FeCl_2$, $Fe(SO_4)_2$, Al_2O_3, $AlCl_3$, $CaCO_3$, $Ca(OH)_2$, HCl, H_2SO_4, and H_3PO_4. Of these the most economical and one of the most effective was $Ca(OH)_2$. The addition of $Ca(OH)_2$ in amounts required (0.3 to 0.5 per cent) to effect suitable pressing characteristics was not objectionable when the dried pulp was used for cattle feed.

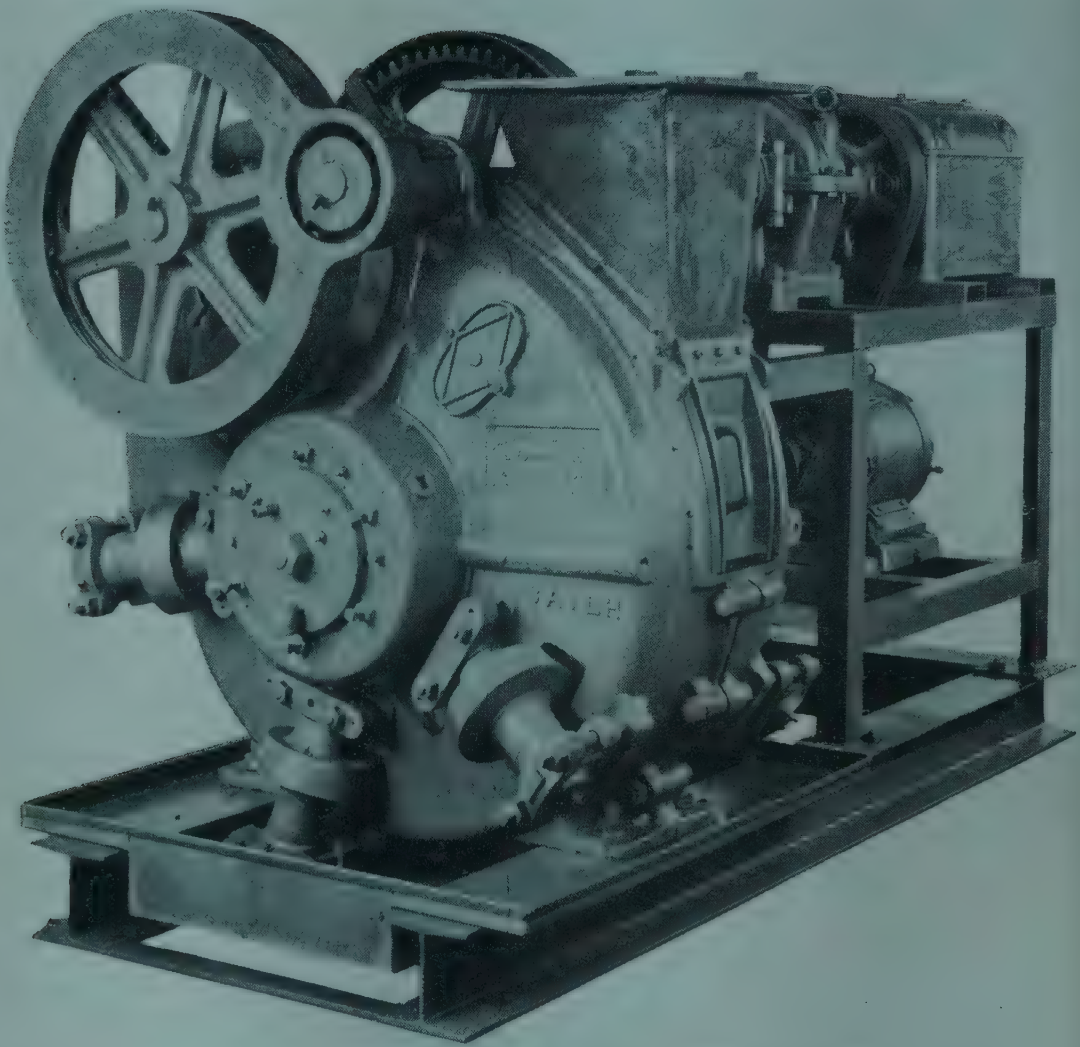


Courtesy of E. D. Jones Sons Co.

FIG. 110. PRESENT VERSION OF ZENITH PRESS USED IN DEWATERING OF LIMED POTATO PULP

When a Zenith Model ZM-10 press was used on limed pulp, press cake moistures varied from 65 to 70 per cent. However uniformly satisfactory pressing with this model was not always obtained. The most modern version of the Zenith press is shown in Fig. 110.

A Davenport 3A press using limed pulp produced press cake with a



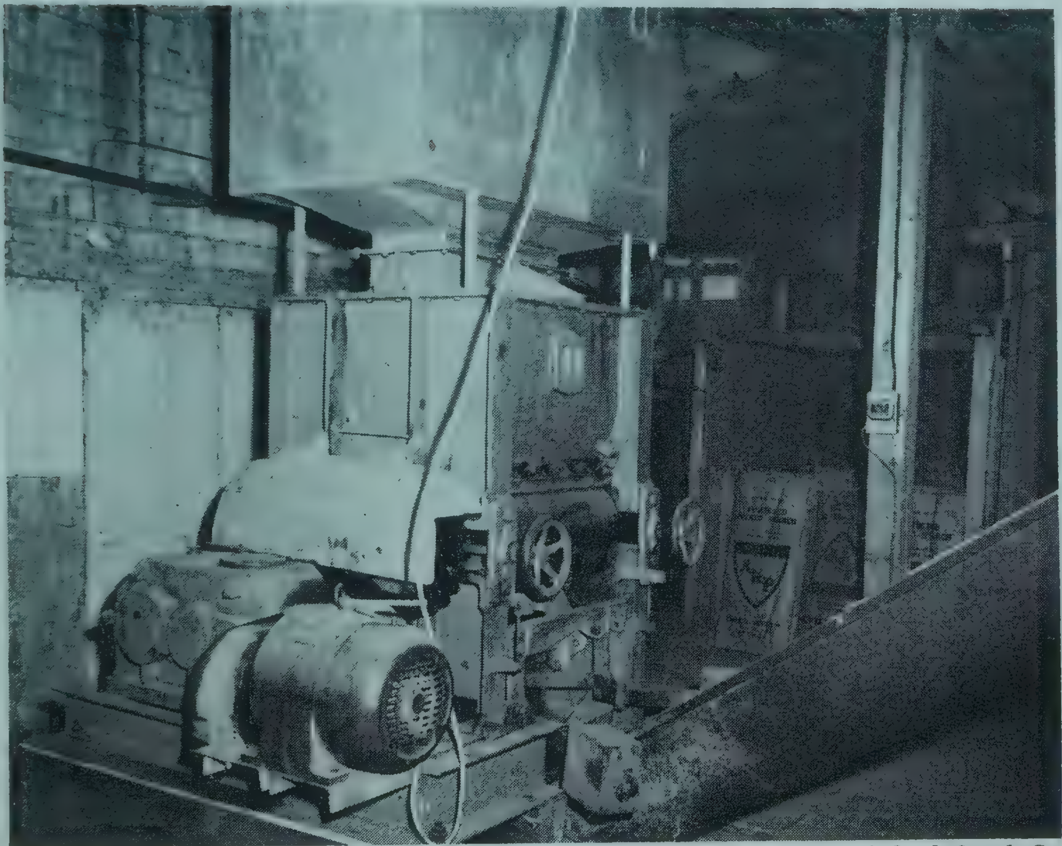
Courtesy of Davenport Machine and Foundry Co.

Fig. 111. Davenport Press Used in Dewatering Limed Potato Starch Plant Waste Pulp

moisture content of 74 to 80 per cent depending on the pressures used. Re-pressing the 74 per cent moisture press cake in the same press reduced the moisture to 58 per cent. The Davenport type press is shown in Fig. 111.

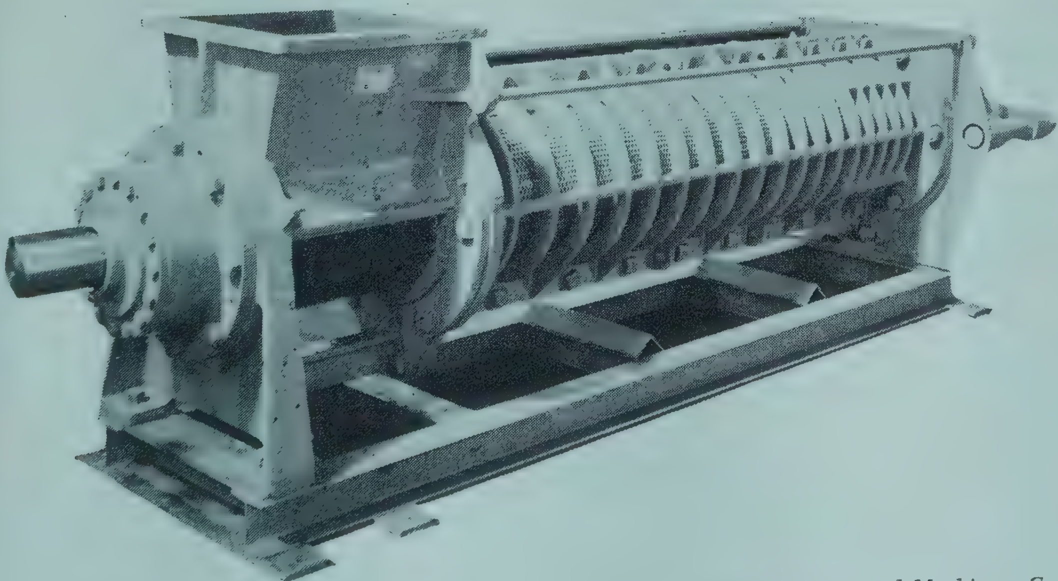
Other types of presses have been used to press untreated potato pulp. Of these the Buttner, a press of German manufacture, Fig. 112, and the Enterprise, Fig. 113, show good results delivering pressed pulp of approximately 80 per cent moisture.

Drying of pressed pulp can be successfully accomplished by a conventional steam tube drier according to Eskew *et al.* (1948) or by a direct-fired rotary drier (Highlands 1951).



Courtesy of Philbrick Starch Co.

FIG. 112. BUTTNER PRESS FOR DEWATERING UNTREATED POTATO STARCH PLANT PULP



Courtesy of Enterprise Engine and Machinery Co.

FIG. 113. ENTERPRISE PRESS USED FOR DEWATERING UNTREATED POTATO PULP

FEEDING POTATO PULP

As mentioned above, feeding of waste potato pulp from starch factories is common practice in certain European countries. In the United States less attention has been paid to this type of use. Dickey and Brugman (1956) used ensiled potato pulp stored in plastic- and sisal-lined bunker silos for feeding heifers. These animals, weighing about 500 lbs, ate

TABLE 64

COMPOSITION OF SILAGE

Component	From Silo with Plastic Liner	From Silo with Sisal Liner
	Per cent	Per cent
Moisture	83.37	83.55
Protein	1.20	1.19
Fat	0.06	0.05
Fiber	1.06	1.05
Mineral	0.51	0.52
Nitrogen-free extract	13.80	13.64

TABLE 65

COMPARISON OF COMPOSITION OF POTATO PULP AND NO. 2 CORN

Component	Dried Potato Pulp	U. S. No. 2 Corn
Water	12.29	15.0
Protein	8.44	8.6
Fat	0.40	3.9
Fiber	5.30	2.0
Ash	4.17	1.2
Nitrogen-free extract	69.40	69.3

TABLE 66

RESULTS OF DIGESTION TRIAL ON DRIED POTATO PULP

Constituent	Average Analysis	Coefficient of Digestibility	Average Digestible Nutrients
	Per cent	Per cent	Per cent
Protein	7.69	77.72	5.98
Fat	0.39	26.67	0.23
Fiber	6.14	63.72	3.91
Nitrogen-free extract	70.27	97.98	68.85
Water	21.31	...	...
Minerals	3.20	...	...

nearly 10 lbs. of silage per head per day in addition to the regular hay ration and 3 lbs. of grain. In many instances the animals showed a preference for the wet potato pulp silage instead of the hay and grain.

Composition of the silage is given in Table 64.

Other studies by Dickey (1955) on feeding dairy cattle with dried

potato pulp stated that when fed at the 22.5 per cent level in mixed feed, pulp had a feed value equal to yellow hominy.

Composition comparison is shown in Table 65.

The digestibility of dried potato pulp has been studied by Dickey and Plummer (1955). In the first trial the authors used 2.5 lbs of dried pulp per 100 lbs. of body weight of the test animals, with 1 lb. of soya bean meal and approximately the same amount of hay. A second test was run using 4 lbs. of dried potato pulp and 1 lb. of soya bean meal and approximately the same amount of hay. A third test was run using 4 lbs. of dried potato pulp and 1 lb. of soya bean meal daily, but without hay. The results of this latter trial are shown in Table 66.

In another report Dickey and Brugman (1957) indicated that dried potato pulp is one of the more versatile feeds when incorporated in mixed feed rations. Furthermore, at $50.00 per ton dried potato pulp compares very favorably in cost with other feeding stuffs at 1957 prices.

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and M. T. Hilborn

Part I. Determination of Total Solids in Raw White Potatoes

The total solids content of potatoes used for dehydration has a profound effect on the yield of dry product per unit weight of the raw stock, i.e., on the overall ratio. The use of high solids potatoes effects savings not only in the cost of the raw material but also in the amount of potatoes handled per unit of finished product, and the amount of water evaporated per unit of finished product. A knowledge of the total solids content is essential if reducing sugars are made on the raw stock. Analyses for reducing sugar are usually made on juice or raw pulp and expressed as per cent of the dry weight. Hence, a determination of total solids should be made on all samples analyzed for reducing sugars. The following method is proposed as a rapid and reasonably accurate method for estimating total solids in raw potatoes.

Sampling.—Select 4 sound tubers from each 10th bag or 2 tubers from each 5th bag as a car is unloaded. An alternate method is to select single tubers at random at regular intervals as potatoes pass over a grader, elevator or endless belt. The intervals should be spaced so that a single tuber will represent not more than 200 lbs. A sample should consist of at least 50 lbs. The sample may be taken after the tubers pass through the washer provided cold water is used for the wash.

Procedure.—Wash the potatoes and allow them to dry. Weigh out a 50-lb. sample as accurately as possible. Split any tubers suspected of having hollow heart. Weigh again, but this time weigh under water with the apparatus described below. The water should be at 68°F. The weight in water of the empty basket should be recorded. It need be checked only occasionally.

Calculations.—If a 50-lb. sample is used the total solids content can be read directly from Table 67 or 68. If the sample weight is other than 50 lbs., specific gravity can be calculated from the formula given below and the corresponding figure for total solids obtained from Table 67 or 68.

$$\text{Specific Gravity} = \frac{A}{A - W}$$

A = weight in air and W = weight in water.

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In making the calculations, the same units (grams or ounces) must, of course, be used for both weights. Weights between those given in Table 67 or 68 can be evaluated by interpolation or by construction of a graph of the points given.

TABLE 67

SPECIFIC GRAVITY AND TOTAL SOLIDS CONTENT OF RAW WHITE POTATOES

Conversion of Weight in Water of a 50-lb. Sample to Specific Gravity and to Total Solids Content

Weight of Sample in Air = 50 lbs. (22,680 Gm.)

Weight of Sample in Water	Specific Gravity	Total Solids
Gm.		Per cent
1,000	1.0461	13.5
1,050	1.0485	14.0
1,100	1.0510	14.5
1,150	1.0534	15.0
1,200	1.0559	15.5
1,250	1.0583	16.0
1,300	1.0608	16.6
1,350	1.0632	17.1
1,400	1.0658	17.7
1,450	1.0683	18.2
1,500	1.0708	18.7
1,550	1.0734	19.3
1,600	1.0759	19.9
1,650	1.0785	20.4
1,700	1.0810	21.0
1,750	1.0836	21.5
1,800	1.0861	22.0
1,850	1.0888	22.6
1,900	1.0914	23.2
1,950	1.0941	23.8
2,000	1.0967	24.4
2,050	1.0994	25.0
2,100	1.1020	25.6

Apparatus.—Any set of scales capable of weighing to within one ounce or less may be used for weighing the 50-lb. sample in air. The same or other scales capable of the same degree of accuracy may be used for weighing in water but since the weight is much smaller it is possible and preferable to use scales of greater sensitivity. The following apparatus has been found to be quite satisfactory. A wire or perforated plate basket (one bushel capacity) was suspended by means of a hook to the carriage below the weighing pan of a three beam solution scales (capacity 20 kg., sensitivity one gram). It was necessary to bore a hole through the base of the scale to accommodate the hook. The scales were then bolted to a wooden plank and the whole set over a 50-gal. galvanized iron water tank. The water was always brought to the same level (sufficient to com-

Table 68

SPECIFIC GRAVITY AND TOTAL SOLIDS CONTENT OF RAW WHITE POTATOES

Conversion of Weight in Water of a 50-lb. Sample to Specific Gravity and to Total Solids Content

Weight of Sample in Air = 50 lbs. (22,680 Gm.)

Weight in Water	Specific Gravity	Total Solids
Oz.		Per cent
32	1.0417	12.6
34	1.0444	13.1
36	1.0471	13.7
38	1.0499	14.3
40	1.0526	14.9
42	1.0554	15.5
44	1.0582	16.1
46	1.0610	16.7
48	1.0638	17.3
50	1.0667	17.9
52	1.0695	18.5
54	1.0724	19.1
56	1.0753	19.7
58	1.0782	20.3
60	1.0810	21.0
62	1.0840	21.6
64	1.0870	22.2
66	1.0899	22.9
68	1.0929	23.5
70	1.0959	24.2
72	1.0989	24.8
74	1.1019	25.5

pletely submerge the basket and contents). Just prior to use, the water was heated to 68°F. with steam.

Any modification of the above may be used provided the following conditions are met.

1. The scales should be of sufficient capacity and sensitivity. (A basket made of iron will weigh approximately 87 per cent as much in water as it does in air.)

2. The basket and contents should be completely submerged.

3. The water should be at approximately 68°F.

4. The water tank should be of sufficient size to prevent any appreciable change in level upon introducing the sample. This level should always be the same.

Remarks.—The correlation of specific gravity with total solids has been found to change appreciably as the length of storage increases. The values given in Tables 67 and 68 are intermediate, corresponding to mid-winter storage. At the beginning of the storage season (recently dug potatoes), the value given for total solids will be about 0.6 per cent (actual) too high. At the end of the storage season, they will be about

0.6 per cent too low. Hence the values given may be adjusted accordingly.

Insufficient data have been obtained to be certain that the values in Tables 67 and 68 will apply to all varieties in all areas.

For a much quicker, simpler and fairly accurate method of measuring specific gravity of potatoes, the potato hydrometer can be used see p. 228–229).

A. Frank Ross

Part II. Dinitrophenol Method For Reducing Sugars

Sampling on Carload Basis.—Take at least two (same number from each bag) sound tubers from each 10th bag as the car is loaded or unloaded. Combine to form a composite sample and mix well by forking over several times or pouring from one container to another. From this composite sample take three 15-tuber samples for sugar analysis. The tubers should be picked at random, rejecting only those that are not sound. This method is suggested as minimum requirements. A better sample would be obtained if more bags were sampled.

Sampling Potatoes Stored in Bulk.—There is no satisfactory method for obtaining a representative sample of potatoes stored in bulk without moving the whole bin. As a bin is emptied, or filled, sampling can be accomplished by picking single tubers at random from the elevator, grader or containers. A tuber should be taken at regular intervals such that each 400 to 500 lbs. will be represented. Each composite sample should represent approximately one carload. Each composite sample should be subdivided as described above.

Preparation of Sample.—Wash and dry each 15-tuber sample. Remove a longitudinal quarter (long cut from stem-end to bud-end) from each tuber. Reject those with internal discoloration. Grind through meat grinder into muslin or gauze bag or large squares placed over a pan or beaker. Squeeze out the juice. Centrifuge the juice and dilute as described below. Avoid delays for long standing may result in enzymatic changes.

Dilution of Juice.—Unless the juice is diluted considerably before use, extraneous compounds in raw juice will cause false values. The exact amount to dilute will depend upon the particular colorimeter used and the amount of reducing sugars present. The lowest dilution recommended is 4 to 50, and the highest, 1 to 100.

Reagent.—If sodium 2,4-dinitrophenolate is available, the reagent is prepared as follows:

Solution A: Dissolve 8 gm. sodium 2,4-dinitrophenolate and 2.5 gm. phenol in 200 ml. of 5 per cent sodium hydroxide.

Solution B: Dissolve 100 gm. Rochelle salt (sodium potassium tartrate) in about 500 ml. of distilled water.

Mix Solution A and B together, then transfer to a 1,000 ml. volumetric flask and make up to 1,000 ml. with distilled water. The water required

to make the desired volume should be used to rinse out the containers in which Solutions A and B were prepared.

If sodium dinitrophenolate is not available, proceed as follows:

Solution A: Dissolve 7.145 gm. 2,4-dinitrophenol in 230 ml. of 5 per cent sodium hydroxide. Heat on steam bath, or hot water bath, until the 2,4-dinitrophenol dissolves. Then add 2.5 gm. phenol. Heat some more if the solution does not remain clear.

Solution B: Dissolve 100 gm. Rochelle salt in about 500 ml. of distilled water.

Mix the two solutions and make up to 1,000 ml. as described above.

Procedure.—Pipette 2 ml. of the diluted juice or alcoholic extract into a 40 to 50 ml. test tube. Add 6 ml. of the dinitrophenol reagent. Mix, then heat on a boiling water bath for exactly 6 minutes. Cool 3 minutes in running water. Transfer a portion to a colorimeter tube and immediately estimate the amount of reducing sugars present. The tubes should not be removed from the cold water until just before readings are made. All necessary adjustments of the colorimeter should be made before the tubes are taken from the cold water. The color is stable for 20 minutes when the tubes are kept cold. Use a filter with maximum absorption at about 600 millimicrons.

Standard Sugar Solutions.—With any photoelectric colorimeter, it will be necessary to prepare a calibration curve using standards prepared from anhydrous glucose. The particular concentrations to use will depend upon the kind of colorimeter available. A stock glucose standard can be made by dissolving 1 gm. of anhydrous glucose in distilled water and making the volume up to 100 ml. This will give a solution containing 10 mg. per ml. and may be diluted to any desired extent. Glucose standards will keep for long periods in the refrigerator provided a crystal of thymol is kept in each. In preparing the calibration curve, the sugar standards are treated exactly as are the juice samples. The calibration curve should be checked occasionally.

Calculations.—Analysis of the potato juice is conveniently expressed as mg. per ml. This can be converted to per cent of the fresh weight by multiplying the factor x /1,000, where x is the per cent moisture in the raw potato. In most cases, satisfactory results can be obtained by assuming 80 per cent moisture. As an example, if a lot contains 80 per cent moisture and the juice contains 15 mg, reducing sugar per ml., the reducing sugar content of the raw potato will be 15 x (80/1,000) or 1.2 per cent. Since the juice is diluted, the exact dilution must, of course, be considered in the calculations.

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